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This thesis formulates the problem of selecting modernization program initiatives for implementation by the Marine Corps as a mixed integer programming problem. The problem is a generalization of the traditional resource allocation problem in operations research. When implemented as a computer system, it offers several enhancements over the system currently used by the Marine Corps planners. The system simultaneously maximizes benefit values and minimizes budget under utilization. When combined with the proposed acceleration procedure, it also allows for rapid "what if" analysis, an extremely useful feature for decision making.

The prototype system was implemented using commercially available software. It is flexible and relatively easy to maintain. Data from the previous Future Year Defense Plan (FYDP) was used to demonstrate the various applications and features of the system.

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# AN OPTIMAL PROGRAM INITIATIVE SELECTION MODEL FOR USMC PROGRAM OBJECTIVE MEMORANDUM PLANNING

by

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Submitted in partial fulfillment
of the requirements for the degree of

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# ABSTRACT

This thesis formulates the problem of selecting modernization program initiatives for implementation by the Marine Corps as a mixed integer programming problem. The problem is a generalization of the traditional resource allocation problem in operations research. When implemented as a computer system, it offers several enhancements over the system currently used by the Marine Corps planners. The system simultaneously maximizes benefit values and minimizes budget under utilization. When combined with the proposed acceleration procedure, it also allows for rapid "what if" analysis, an extremely useful feature for decision making.

The prototype system was implemented using commercially available software. It is flexible and relatively easy to maintain. Data from the previous Future Year Defense Plan (FYDP) was used to demonstrate the various applications and features of the system.

# THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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# I. INTRODUCTION

## A. OVERVIEW OF MARINE CORPS BUDGETARY PLANNING

The budgetary system utilized within the Department of Defense (DOD), the Department of the Navy (DON), and the Marine Corps is an extremely complex and dynamic process that requires continual attention and the constant coordination of all involved. The DOD Planning and Programming Budgeting System (PPBS) is designed to allocate the limited resources among numerous competing requirements in order to fund, operate, and support effective military forces to protect the country's national security interests.

For their part in this planning process, Marine Corps planners have the responsibility of determining the most effective use of resources to ensure the best fit of mission and means in today's complex and dynamic national security environment. Factors considered in the planning and programming process include (1) the cost of the individual project, (2) the benefit of the project to the Marine Corps, (3) projected budget constraints, (4) status of current equipment, (5) both current and desired warfighting capabilities, (6) strategic and operational plans, and (7) planning guidance provided by the Secretary of Defense

(SECDEF), Secretary of the Navy (SECNAV), and the Commandant of the Marine Corps (CMC).

The Marine Corps currently allocates between six and nine percent of its annual budget to the development and acquisition of modernization programs. This corresponds to an investment of over four billion dollars spread across a six year planning horizon. The task of allocating these resources among approximately 250 competing, and often times interdependent programs, is an extremely difficult one. The current trend toward smaller force structures and declining defense budgets makes the judicious allocation of limited resources a critical issue. The absence of an optimization model specifically designed to solve this resource allocation problem degrades the Marine Corps' ability to receive the greatest benefit from its investment dollars.

## B. STUDY GOAL

The goal of this thesis is to develop an optimization model designed to assist the Marine Corps in determining a plan for scheduling and procuring the programs that provide the greatest overall benefit to the Marine Corps. In addition, it is hoped that the results described in this thesis illustrate the enormous potential of mathematical programming models as decision making aids and further encourage the Marine Corps to employ this methodology in the future.

## C. THESIS ORGANIZATION

Chapter II describes the current Marine Corps methodology for determining the allocation of its limited resources as well as prior research in this area. Chapter III presents the formulation of a mixed integer programming (optimization) model designed to assist Marine Corps planners in determining an optimal allocation of resources. Chapter IV discusses the implementation of the model on an actual Marine Corps planning and programming problem using commercially available software. Chapter V demonstrates various applications of the model on the sample problem and presents an analysis of these results. Chapter VI summarizes the findings of this thesis and suggests topics for further research.

# II. BACKGROUND

## A. DEVELOPMENT OF MARINE CORPS PROGRAM OBJECTIVE MEMORANDUM

The purpose of the Program Objective Memorandum (POM) is to express the Marine Corps total requirements in terms of force structure, modernization and support requirements, manpower, and acquisition to carry out the current strategic and operational plans. The POM development process is based on a six year planning cycle known as the Future Year Defense Plan (FYDP) and is updated every two years. The development process officially begins when the SECDEF imparts his Defense Planning Guidance to the SECNAV, who in turn provides his planning guidance to the Navy and Marine Corps. Since the Marine Corps is a part of the DON, its POM is developed as part of the DON POM rather than as an independent Marine Corps POM. SECNAV establishes specific areas of responsibility for POM development between the Navy and Marine Corps. For example, currently the Marine Corps' planning effort for personnel and ground-warfare capability is virtually autonomous from the Navy planning effort, while the Marine Corps effort for air warfare and other program areas occurs jointly with the Navy staff. With respect to the Marine Corps' specific areas of responsibility, the Marine Corps

staff operates under fiscal and programmatic guidance defined by the SECNAV and CMC. The SECNAV, in consultation with CMC and the Chief of Naval Operations (CNO), determines the so called "blue-green split" that divides the multi-level, multi-year dollar totals for the Department of the Navy between the Navy and Marine Corps programmers. Typically, this split allocates between 10 and 20 percent of the DON budget to the Marine Corps. Given this overall fiscal constraint, the Marine Corps develops a "green dollar" POM, which is reviewed by SECNAV and subsequently incorporated into the overall DON POM. [Ref. 1]

## B. PROCUREMENT PRIORITIZATION PROCESS

Upon receiving the fiscal guidance provided by the SECNAV, the Marine Corps further divides its dollars into the following major areas: (1) manpower, (2) operations and maintenance, (3) reserve component, (4) military construction, and (5) procurement. This thesis focuses exclusively on the allocation of resources designated specifically for procurement of modernization programs.

### 1. Development of Programming Initiatives

The Marine Corps procurement process begins with the formulation of projects into specific programs or initiatives. To make the prioritization process effective, these initiatives must be mission-oriented, independent, and fully executable. First, an initiative is mission-oriented if it

provides a capability not currently available or enhances an existing capability. Second, an initiative is independent if it does not depend strongly on the capabilities nor funding of other initiatives. However, often times dependence occurs between certain complex items such as command and control systems or communication equipment. Finally, an initiative is executable if it takes into account all the elements required for implementation. These elements include the funding required for the initiative, as well as the training, operations, maintenance, and manpower required to support the initiative.

### 2. Determination of Benefit Values

During this phase of the process, each initiative must be assigned a benefit value representing the initiative's "utility" to the Marine Corps. During POM-94, there were approximately 250 initiatives representing a total value of over 11 billion dollars. These initiatives can be vastly different. For example, they can represent procurement programs for tanks, command and control systems, mobile electric power generators or material handling equipment as well as construction projects for family housing and command headquarters. Judging from the nature of these initiatives, it is difficult, if not impossible, to develop a quantitative technique for accurately assigning representative benefit values. One difficulty stems from the fact that the term

"benefit" is not well defined, thereby making it impossible to measure. The approach taken by the Marine Corps planners is subjective; however, it does contain logical and well structured computational steps.

First, all initiatives are separated into groups based on the primary mission area they are designed to benefit such as artillery, armor, logistics, or communications. The basic idea is that initiatives within the same mission area can be more easily compared against each other. With the help of mission area specialists, Marine Corps programmers assign benefit values to initiatives in each mission area. These values represent a ranking of each initiative individually and a ranking of groups of initiatives as well. For example, consider the following initiatives and their benefit values in a given mission area.

| Initiative | Benefit Value |
|---|---|
| A | 100 |
| B | 60 |
| C | 45 |
| D | 30 |
| E | 10 |

Based on the above values, relationships among groups of initiatives can be inferred. For example,

- A is worth less than the combination of B and C since 100 is less than (60 + 45 = 105),

- The combination of A and E is worth more than the combination of B and D since (100 + 10 = 110) is greater than (60 + 30 = 90),

- B is worth more than the combination of D and E, but less than the combination of C and D since 60 is greater than (30 + 10 = 40), but less than (45 + 30 = 75).

To facilitate the task of selecting the initiatives for funding, the benefit values from the different mission areas must be integrated (or adjusted) so that values from different areas can be compared. This adjustment involves selecting three initiatives with high, medium, and low benefit values from each mission area. The selected initiatives are then briefed to the Program Evaluation Group (PEG) who independently determines an additional set of benefit values. The PEG's benefit values represent the "cross-mission benefits" which serve as a basis of computing an adjustment or weighting factor for the benefit values in each mission area. The complete details of this process are fully documented in Reference [2]. However, to illustrate the basic concept underlying the process of computing the weighting factors, consider the following example.

| Mission Area 1 | | Mission Area 2 | |
|---|---|---|---|
| Initiative | Benefit | Initiative | Benefit |
| A1 | 100 | A2 | 100 |
| B1 | 60 | B2 | 70 |
| C1 | 34 | C2 | 25 |
| | | D2 | 15 |

To simplify the explanation, assume that only one initiative from each of the two mission areas, B1 and A2, are selected for briefing to the PEG who assigns a benefit value of 100 to A2 and 30 to B1. Since the PEG benefit value for initiative A2 is the same as before, no adjustments are necessary for initiatives in Area 2, i.e., the weighting factor is 1. For initiative B1, its benefit value decreased by 50% from 60 to 30. This implies that the benefit values of all initiatives in Area 1 must be adjusted downward by 50% in order for them to remain consistent with the benefit of B1. In this case, the benefit values in Area 1 are multiplied by the weight of 0.5. This procedure results in the following combined list of benefit values for the two mission areas. This is defined as the benefit-ordered list of initiatives.

| Initiative | Benefit |
|---|---|
| A2 | 100 |
| B2 | 70 |
| A1 | 50 |
| B1 | 30 |
| C2 | 25 |
| C1 | 17 |
| D2 | 15 |

After the benefit value of each initiative is determined, a cost-benefit ratio for each initiative is computed. The initiatives are then listed in order of their cost-benefit

ratios, with the smallest cost-benefit ratio listed first, representing the initiative containing the highest benefit value per dollar. Table 1 depicts the cost-benefit ratio ordered list of initiatives.

**TABLE 1. COST-BENEFIT RATIO ORDERED LIST**

| FUNDING ORDER | INITIATIVE | COST(MIL) | BENEFIT VALUE | COST-BENEFIT RATIO |
|---|---|---|---|---|
| 1 | C1 | 4.0 | 17 | 0.24 |
| 2 | C2 | 7.5 | 25 | 0.30 |
| 3 | B2 | 35.0 | 70 | 0.50 |
| 4 | D2 | 29.0 | 15 | 1.93 |
| 5 | A1 | 100.0 | 50 | 2.00 |
| 6 | A2 | 250.0 | 100 | 2.50 |
| 7 | B1 | 150.0 | 30 | 5.00 |

### 3. Selection of Initiatives

The main objective of the initiative selection process is to maximize the total benefit value of the initiatives selected for procurement. In an attempt to achieve this objective, the POM Working Group (PWG) uses a heuristic approach developed by Decisions and Designs, Inc., [Ref. 3]. The PWG uses the cost-benefit ratio ordered list as its starting point in determining which initiatives to select. Beginning with the smallest cost-benefit ratio initiative and continuing in increasing value of the cost-benefit ratio, the PWG determines whether or not to include the initiative under consideration in the Marine Corps POM submission. In addition

to the cost-benefit ratio, the PWG also takes into account the benefit value of the initiative, the planning guidance received from higher headquarters, and the personal experience and professional knowledge of the working group to make a decision concerning each initiative. The total cost of the initiatives selected continues to accumulate until the budget limit is reached. The PWG continues to revise this "buy list" of initiatives by adding or deleting initiatives until it feels that the most beneficial mix of initiatives has been selected.

# III. OPTIMAL PROGRAM INITIATIVE SELECTION (OPIS) PROBLEM

The problem faced by Marine Corps planners is well known in the operations research community as the resource allocation or capital budgeting problem. In their most basic form, the two problems are combinatorial problems known as the knapsack problem. The name "knapsack" is descriptive and derived from an application in the sport of hiking or camping. A hiker or camper usually takes along a backpack during a hiking or camping trip. This backpack is used to carry items, each of which provides the camper or hiker a certain utility or benefit during the trip. However, they also take up room in the backpack which has a finite capacity. If the capacity is sufficiently large, the hiker or camper can bring every item he or she desires, however, when the capacity is insufficient for every item, the hiker or camper must leave some items behind. In the latter case, the hiker or camper desires to take the combination of items that provide him or her with the maximum benefit.

Applications of the resource allocation or capital budgeting problem are many. In finance, the application is in the area of portfolio management. In this case, the portfolio manager must determine how the portfolio's resources should be invested, i.e., stocks, bonds, mutual funds, cd's, etc. To

make an analogy with the hiking example, the stocks, bonds, or other investment opportunities are items to take on a camping trip and the size of the available resources in the portfolio is simply the capacity of the backpack. The objective in managing the portfolio is to maximize profit (or return on investment) in terms of interest, dividends, and capital gains received through the various investments. In research and development, companies or federal agencies must decide which R&D projects to fund from an annual budget. In terms of the basic knapsack problem, the projects represent items to take on the trip and the size of the budget corresponds to the capacity of the knapsack. The objective here is to maximize benefit or profit from these R&D projects. Similarly, in advertising, the problem is to select among the various advertising strategies, e.g., television, radio, and newspaper, in order to maximize product exposure and sales volume. The above examples are only three applications. A complete list would be too long to list here.

However, there is continued interest in the applications of the resource allocation and capital budgeting problem. Recently, Khorramshahgol and Steiner [Ref. 4] used the capital budgeting problem to evaluate the numerous rural road projects for the Division of Transportation of the US Department of Interior. Habeeb [Ref. 5] used the resource allocation problem to assist Nigeria in allocating the country's scarce resources among numerous competing sectors. From the military

side, Donahue [Ref. 6] developed a resource allocation model to assist US Army planners in designing an optimal investment strategy for modernization programs. Anderson [Ref. 7] also proposed a similar model for allocating funds to R&D programs for the US Army Strategic Defense Command.

Among the recent military applications, the model in Reference [6] by Capt. Donahue is the one most similar to the model presented in the next section. However, the inherent difference between the structural organization and planning processes of the Marine Corps and Army require a different although somewhat similar approach. Capt. Donahue's model is formulated using a goal programming approach and specifically determines the funding level for each program based on an aspired funding level and other competing objectives over a fifteen year planning horizon. In contrast, the Marine Corps uses a six year planning horizon where the contents and costs of each program are typically very well defined and very specific. These fully detailed programs are then either funded completely or not at all. In contrast to Donahue's model, the model in this thesis determines the specific year in the planning cycle that each program will begin receiving funding and permits the planner to make modifications to the start year of each program.

## A. PROBLEM STATEMENT

The problem of purchasing program initiatives for the Marine Corps can be viewed as a multi-period resource allocation problem with complicating or side constraints. The Marine Corps planners must select which program initiatives to purchase with the objective of maximizing the total benefit to the Marine Corps. However, most program initiatives require multi-year funding and take several years to complete. Once a multi-year initiative is selected, funding must be allocated from the budgets of future years to finance the complete initiative funding schedule beyond the initiative's starting year.

In addition to the purchasing decision, the Marine Corps planner must schedule what year to fund the selected initiatives. The FYDP is six years and the planners only consider initiatives that are available for purchase during the planning horizon. Funding can begin in any year of the FYDP after the initiative is available for purchase. Thus, initiatives requiring funding in the first year of the FYDP can have up to six individual funding schedules. The first funding schedule starts in the first year of the FYDP and the sixth one begins in the last year of the FYDP.

In many cases, program initiatives may be related in some logical manner. The model in the next section is designed to handle three different logical relationships. First is the competitive relationship. This occurs when two or more

initiatives provide the same or similar mission capability. In this case, at most one of these initiatives should be purchased. Second is the dependent relationship. This happens when one or more (secondary) initiatives may be dependent upon another (or primary) initiative in that the secondary initiatives should be purchased only if the primary initiative is purchased. One example of such a relationship is the purchase of a certain truck and a separate trailer specifically designed for that truck. Clearly, the trailers should not be purchased unless the truck is also purchased. The last is the complementary relationship. In this relationship, some initiatives must be purchased in groups or cohorts. If any initiative in the group is purchased, the rest of the initiatives must also be purchased. Examples of this type of interdependence normally occur when considering complex communication networks or command and control systems.

## B. MATHEMATICAL FORMULATION

Below is a mixed integer programming formulation of the problem described in the previous section.

**Indices:**

| | | |
|---|---|---|
| $i, j =$ | $1, \ldots I$ | program initiatives |
| $s =$ | $1, \ldots S$ | funding schedules |
| $y =$ | $1, \ldots Y$ | year of FYDP (planning cycle) |
| $m =$ | $1, \ldots M$ | mission areas |
| $n =$ | $1, \ldots N$ | set of logical relationships |

**Index Sets:**

$\Omega_n$ Index set (group) of initiatives from which only one initiative i can be selected (competing relationship)

$\Gamma_i$ Index set (group) of initiatives whose purchase depends on initiative i (dependent relationship)

$\Phi_n$ Index set (group) of a combination of initiatives that must all be purchased if any initiative in the group is purchased (complementary relationship)

**Given and Derived Data:**

$b_i$ benefit value of initiative i

$c_{i,s,y}$ cost of initiative i using funding schedule s in year y

$l_y$ budget limit in year y

$p_y$ penalty for deviation below budget limit in year y

**Nonnegative Variables:**

$D_y$ deviation below budget limit in year y

**Binary Variables:**

$X_{i,s}$ decision variable equaling one if initiative i is purchased using funding schedule s, zero otherwise

$Z_n$ binary variable used in logical constraints

**Formulation:**

<u>OPTIMAL PROGRAM INITIATIVE SELECTION (OPIS) MODEL</u>

$$MAXIMIZE \quad \sum_i \sum_s b_i X_{i,s} \quad - \quad \sum_{y=1}^{2} p_y D_y$$

Subject to:

$$\sum_i \sum_s c_{i,s,y} X_{i,s} \quad + \quad D_y \quad = \quad l_y \qquad \forall\, y \tag{1}$$

$$\sum_s X_{i,s} \quad \leq \quad 1 \qquad \forall i \tag{2}$$

$$\sum_{i \,\in\, \Omega_n} \sum_s X_{i,s} \quad \leq \quad 1 \qquad \forall n \tag{3}$$

$$|\Gamma_i| \sum_s X_{i,s} \quad - \quad \sum_{j \in \Gamma_i} \left(\sum_s X_{j,s}\right) \quad \geq \quad 0 \qquad \forall i \tag{4}$$

$$\sum_{i \,\in\, \Phi_n} \sum_s X_{i,s} \quad \geq \quad |\Phi_n| Z_n \qquad \forall n \tag{5}$$

$$\sum_s X_{i,s} \quad \leq \quad Z_n \qquad \forall n, i \in \Phi_n \tag{6}$$

In the above Optimal Program Initiative Selection (OPIS) Model, the objective is to maximize the total benefit value from the purchase of the selected initiatives (the first term in the objective function) and, at the same time, minimize the under-utilization of the annual budgets (the second term).

Without this term the model may choose a purchasing plan which utilizes, say, only 80% of the budget in the first year of the FYDP. In today's environment of shrinking military budgets, these budget utilization shortfalls will prove detrimental to the size of future budgets. Therefore the Marine Corps and planners in other military services normally require that the budget be fully utilized. The second term in the objective function satisfies this requirement by assessing a penalty for every dollar unused during the first two years of the FYDP. Since the POM process is repeated every two years, the utilization level of budgets beyond the second year is not critical and is therefore not penalized when under utilized.

Constraint (1) ensures that the sum of the costs of all initiatives purchased is less than or equal to the budget limit for each year. The variable $D_y$ in this constraint simply measures the amount of under-utilization in year y. Constraint (2) allows the model to select at most one funding schedule for each initiative. Constraints (3) through (6) express the logical relationships among initiatives. Constraint (3) permits at most one initiative to be selected from a group that provides the same mission capability. Constraint (4) guarantees that secondary initiatives are purchased only if their primary initiatives are purchased. Constraints (5) and (6) in combination specify that, if an

initiative from a group or cohort is purchased, the entire cohort must be purchased.

Chapter IV describes the implementation of this model and the data input formats required to determine the optimal allocation of resources for a Marine Corps procurement planning problem.

# IV. MODEL IMPLEMENTATION AND RESULTS

The OPIS model developed in Chapter III was implemented in the General Algebraic Modeling System or GAMS. [Reference 8]. The complete listing of the OPIS model in GAMS is in Appendix A. GAMS is a high level computer system for representing complex optimization problems precisely and compactly. Although, the resulting optimization problem can be solved by a number of commercially available software programs, the general integer programming solver XA [Ref. 9] was used to solve all optimization problems in this investigation. Both GAMS and XA are available on the Amdahl 5990-500 at the Naval Postgraduate School, which is also the computer used to produce all results reported here.

The remainder of this chapter consists of (i) a description of the input data used to demonstrate the OPIS model, (ii) GAMS implementation of the logical relationships among initiatives, (iii) an acceleration procedure for obtaining a solution to OPIS, (iv) a procedure for selecting an appropriate penalty value to minimize budget under-utilization and (v) descriptions of the post-optimality summary reports from OPIS.

## A. INPUT DATA

The Requirements and Programs (R&P) Division at Headquarters Marine Corps (HQMC) provided information on 234 program initiatives for testing, validation, and analysis. These initiatives were under consideration for procurement during POM-94 and have a total cost of approximately 11 billion dollars. The annual estimated budget limits used for the planning cycle are depicted in Table 2.

**TABLE 2. BUDGET LIMITS UTILIZED FOR POM-94 FYDP**

| FISCAL YEAR | BUDGET LIMIT |
|---|---|
| FY94 | $527,198,000 |
| FY9[illegible] | $548,015,000 |
| FY96 | $609,715,000 |
| FY97 | $758,027,000 |
| FY98 | $881,113,000 |
| FY99 | $928,507,000 |

Table 3 provides the complete information on 25 of the 234 initiatives. Initiative names, benefit values, and funding profiles were obtained from the original data provided by R&P Division, HQMC. Note that the funding profiles are simply the annual funding level required for each initiative during the FYDP. The mission area (second column) and starting year (third column) were added to facilitate the implementation in GAMS as well as enhance the flexibility of the model. The number in the second column indicates the mission area to

which each initiative belongs. Table 4 provides the corresponding mission area names for the numbers in column two. This information is used to produce summary reports from the results of OPIS. Extensions and modifications to the OPIS model based on specific mission area requirements are also possible. The third column in Table 3 allows OPIS users to specify the desired starting year for each project. The starting year indicates the specific year that funding for each program should begin. For example, the initiative AN/TCR-170 is designated to start in FY95 in which case its funding profile (in thousands of dollars) is as follows:

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 0 | 599 | 70 | 0 | 0 | 0 |

Note that this series of funding is obtained by shifting the funding profile for AN/TRC-170 in Table 3 to the right by one year. However, each yearly cost is also adjusted forward in the future by the discounting factors provided by R&P and displayed in Table 5.

TABLE 3. A SAMPLE OF 25 PROGRAM INITIATIVES FOR POM-94

| INITIATIVE NAMES | MISSION AREA | STARTING YEAR | BENEFIT VALUE | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|---|---|---|
| AN/TRC-170 | 12 | 95 | 83.077 | 581 | 68 | 0 | 0 | 0 | 0 |
| GPS-S | 2 | 0 | 58.217 | 2283 | 0 | 0 | 0 | 0 | 0 |
| AN/PSC-3 U | 12 | 0 | 89.768 | 0 | 1872 | 3008 | 274 | 264 | 81 |
| IAS SUITES | 14 | 0 | 42.140 | 1474 | 105 | 238 | 105 | 247 | 105 |
| NBC HAZ | 6 | 0 | 23.663 | 1010 | 950 | 13 | 5 | 9 | 9 |
| T ELEC KEY | 25 | 0 | 5.529 | 95 | 64 | 320 | 30 | 0 | 0 |
| SWITCH UG | 25 | 0 | 9.114 | 300 | 220 | 110 | 60 | 360 | 60 |
| FUEL DEL | 17 | 0 | 16.501 | 0 | 0 | 2113 | 8 | 198 | 8 |
| FB OPTIC D | 25 | 0 | 9.114 | 60 | 90 | 204 | 170 | 170 | 700 |
| AN/PSC3 RE | 12 | 0 | 33.386 | 2257 | 2442 | 201 | 91 | 70 | 70 |
| IDASC IMP | 11 | 0 | 79.208 | 3462 | 3402 | 3761 | 3203 | 355 | 367 |
| AN/MRC-142 | 12 | 0 | 55.976 | 11770 | 0 | 0 | 0 | 0 | 0 |
| AN/TSQ-130 | 14 | 0 | 9.278 | 1738 | 72 | 36 | 36 | 36 | 36 |
| UHF RELAY | 12 | 0 | 12.961 | 1706 | 234 | 105 | 86 | 86 | 86 |
| M&RA ADP | 24 | 0 | 4.005 | 287 | 302 | 216 | 51 | 53 | 55 |
| ELECT TMDE | 28 | 0 | 11.000 | 676 | 680 | 515 | 349 | 351 | 184 |
| COMSEC CAB | 12 | 0 | 30.907 | 3305 | 1317 | 907 | 786 | 662 | 663 |
| SHOP SET | 16 | 0 | 2.466 | 0 | 660 | 5 | 5 | 5 | 5 |
| ENVIRON EQ | 27 | 0 | 11.500 | 610 | 664 | 633 | 696 | 644 | 713 |
| GPS IU | 12 | 0 | 10.796 | 2788 | 150 | 95 | 140 | 140 | 185 |
| MOB ROAD B | 5 | 0 | .682 | 52 | 50 | 58 | 58 | 26 | 33 |
| TRSS PHS V | 14 | 0 | 36.752 | 9577 | 2100 | 1450 | 650 | 700 | 700 |
| CPT SWITCH | 25 | 0 | 12.700 | 6000 | 0 | 0 | 0 | 0 | 0 |
| EDI MODELS | 24 | 0 | 1.256 | 107 | 107 | 107 | 107 | 107 | 107 |
| UHF SATCOM | 12 | 0 | 4.403 | 918 | 973 | 155 | 59 | 43 | 43 |
| LAV FUEL F | 17 | 0 | 3.200 | 0 | 0 | 1108 | 273 | 18 | 18 |

TABLE 4. MARINE CORPS MISSION AREAS

| MISSION AREA NUMBER | MISSION AREA |
|---|---|
| 1 | LAV |
| 2 | ARTILLERY |
| 3 | ARMOR |
| 4 | AAV/AAA |
| 8 | ENGINEER |
| 9 | NBC |
| 7 | RECON |
| 8 | TDEW |
| 9 | INF/ANTIARMOR |
| 12 | NED |
| 11 | AIR C3 |
| 12 | COMM |
| 13 | COMPUTERS |
| 14 | INTELL |
| 18 | MOTOR TRANSPORT |
| 16 | ENGINEER2 |
| 17 | LOGISTICS |
| 18 | LAV |
| 16 | ASSAULT SUPPORT |
| 20 | AIR DEFENSE |
| 21 | TRNG & EDUC |
| 20 | MINE CTRMEASURE |
| 24 | ISWG |
| 24 | BASE/STA COMM |
| 25 | PHYSICAL SECURE |
| 26 | PMC OTHER (I&L) |
| 27 | PST |

TABLE 5. MARINE CORPS INFLATION FACTORS

| FISCAL YEAR | INFLATION FACTOR |
|---|---|
| 94 | 1.03420 |
| 95 | 1.06563 |
| 96 | 1.09973 |
| 97 | 1.13492 |
| 98 | 1.17124 |
| 99 | 1.20871 |

## B. LOGICAL RELATIONSHIPS

Recall from Chapter III that OPIS allows three types of logical relationships among initiatives. Each relationship is re-described below for completeness.

### 1. Competing Initiatives

This set contains groups of initiatives that fulfill the same mission capability and at most one initiative from each group should be purchased. A simple example of competing initiatives are (1) an initiative to purchase a new weapon system to replace the old system, and (2) an initiative to upgrade the existing weapon system. The model ensures that either the new weapon system or the upgraded version is purchased, but not both. Purchasing neither initiative is also a valid option.

### 2. Dependent Initiatives

The initiatives in this group consist of primary and secondary initiatives. The latter are typically additions,

extensions and/or enhancements of the first. In other words, secondary initiatives are supplementary to the primaries. Thus, the purchase of the secondary initiatives must be contingent on the purchase of the primaries. A straightforward example is an initiative to buy a truck and an initiative to buy a trailer specifically designed for that truck. Clearly, the trailer should not be purchased unless the truck is also purchased. The option of only purchasing the truck is also available.

### 3. Complementary Initiatives

The initiatives in this group are complementary to each other and should be purchased in an all-or-nothing manner, i.e., either purchase all initiatives in the group or nothing. In this case, each individual component contains no value unless additional components are also purchased. This type of interaction normally occurs when considering complex systems such as communication networks or command and control systems.

The GAMS implementation of competing initiatives is straightforward. The other two require additional constructs to simplify user interface. In Reference [6], Donahue requires users to modify the equation (constraint) definitions every time there is a change in the logical relationship. However, this requires users to be knowledgeable in GAMS as well as mathematical programming. To avoid this, our

implementation uses a matrix of 0 and 1 elements to indicate dependent and complementary relationships among initiatives.

To illustrate, consider five initiatives, (A,B,C,D,E), with the following dependent relationships. The purchase of initiative C is dependent upon the purchase of A, while the purchase of initiatives D and E are dependent on the purchase of B. In GAMS, these relationships are represented in the form of the table listed below:

```
TABLE DEPENDENT(i,j)

        C    D    E
  A     1    0    0
  B     0    1    1   ;
```

Using the above table and the following GAMS equation for constraint (4) in the OPIS model,

```
CONDITION(i)..
      SUM(j,DEPENDENT(i,j))*SUM(s,X(i,s))
         - SUM(j,DEPENDENT(i,j)*SUM(s,X(i,s)) =G= 0;
```

GAMS would generate the following constraints: (Here, the set S contains the elements S1, S2, and S3 representing three possible funding schedules),

$$X(C,S1)+X(C,S2)+X(C,S3)-X(A,S1)-X(A,S2)-X(A,S3) =L= 0 \tag{7}$$

$$\begin{gathered}X(D,S1)+X(D,S2)+X(D,S3)+X(E,S1)+X(E,S2)+X(E,S3)\\ -2*(X(B,S1)+X(B,S2)+X(B,S3)) =L= 0\end{gathered} \tag{8}$$

If the sum of X(A,S1) + X(A,S2) + X(A,S3) equals one, then initiative A is purchased and equation (1) permits C to be purchased since the sum of X(C,S1) + X(C,S2) + X(C,S3) can be either zero or one. However, if the sum of X(A,S1) + X(A,S2) + X(A,S3) equals zero, then the sum of X(C,S1) + X(C,S2) + X(C,S3) must also be zero. This implies that initiative C cannot be purchased unless A is also purchased. The analysis for equation (2) and initiatives B, D, and E is similar.

For the case involving complementary relationships, consider three initiatives (F,G,H) with the following relationship. If any initiative in this group is purchased, then all three must be purchased. Again, in GAMS this relationship is depicted in the form of the table listed below:

**TABLE COMPLEMENT (n,i)**

| | F | G | H | |
|---|---|---|---|---|
| **N1** | 1 | 1 | 1 | . |

Using the above table and the following pair of GAMS equations,

```
IFTHEN1(N)..
       SUM((i,s)$COMPLEMENT(n,i),X(i,s)
         - SUM(i,COMPLEMENT(n,i))*Z(n)  =G=  0  ,

IFTHEN2(n,i)$COMPLEMENT(n,i)..
       SUM(s,X(i,s))  -  Z(n)  =L=  0  ;
```

GAMS would generate the following constraints:

$$\begin{aligned}&X(F,S1)+X(F,S2)+X(F,S3)+X(G,S1)+X(G,S2)+X(G,S3)\\&\quad+X(H,S1)+X(H,S2)+X(H,S3)-3*Z(N1)\ =L=\ 0\end{aligned} \tag{9}$$

$$X(F,S1)+X(F,S2)+X(F,S3)-Z(N1)\ =L=\ 0 \tag{10}$$

$$X(G,S1)+X(G,S2)+X(G,S3)-Z(N1)\ =L=\ 0 \tag{11}$$

$$X(H,S1)+X(H,S2)+X(H,S3)-Z(N1)\ =L=\ 0 \tag{12}$$

For example, in equation (10) if the sum of X(F,S1) + X(F,S2) + X(F,S3) equals one, then the binary variable Z(N1) must be set equal to one. Consequently, from equations (9), (11), and (12) the sum of X(G,S1) + X(G,S2) + X(G,S3) and the sum of X(H,S1) + X(H,S2) + X(H,S3) must both equal one. In this case, the purchase of initiative F forced the purchase of initiatives G and H. Likewise, the purchase of initiative G or H in equations (11) or (12) respectively will produce the same effect in equation (9).

This ability to easily define logical relationships among initiatives greatly simplifies the user interface with the

model and requires no specific mathematical programming techniques or GAMS implementation knowledge.

## C. ACCELERATION PROCEDURE

In order for OPIS to serve a useful function for Marine planners, it is imperative that OPIS provide a solution in a relatively short period of time, ideally less than five minutes. One method is to allow the XA solver to stop execution when a near optimal solution is found. By the nature of the widely used Branch and Bound method, it is too time consuming to find a theoretically provable optimal solution to an interger programming problem. Near optimal solutions around 10% of optimality are generally regarded as an acceptable standard.

In some cases, 10% of optimality still requires an unacceptable amount of cpu time. To further reduce this computational effort, a two phase approach is developed to accelerate the process. The approach is based on the observation that the linear programming relaxation of OPIS yields a solution with only approximately 10% of the binary variables having noninteger values. The model then examines the optimal level of the binary decision variables and fixes those variables whose optimal value is exactly equal to one. Once a decision variable for a specific initiative is fixed, all remaining variables pertaining to that initiative, i.e., the alternative funding profiles, are set equal to zero.

Subsequently, all constraints involving these variables are removed during the next generation of the model. The model then resolves this modified problem, however, this time the model continues until an integer solution is found. The basic idea behind this approach is that by fixing a large percentage of the decision variables and consequently also consuming a large percentage of the available resources, the size of the model is greatly reduced and an integer solution can be found in less time.

To empirically validate the effectiveness of this two phase method, 25 random problems were generated and solved. For a given random problem, each of the 234 initiatives has a certain probability of being included in the problem. The annual budget limits for each problem are computed using this same probability to represent a proportional level of available funding. For example, if each initiative has a probability of 0.80 of being included in a given problem, then the annual budget limits will be set at 80% of their original value. This enables the ratio of the budget limit to the total cost of all initiatives under consideration to remain approximately constant for each problem. Table 6 depicts the results of this two phase method versus the standard method for the sample problems tested.

TABLE 6. RESULTS OF ACCELERATION PROCEDURE

| | | STANDARD METHOD | | TWO PHASE METHOD | | | |
|---|---|---|---|---|---|---|---|
| PROBLEM | PROBABILITY INITIATIVE INCLUDED | BENEFIT VALUE | CPU TIME (sec) | BENEFIT VALUE | CPU TIME (sec) | DIFFERENCE BENEFIT VALUE | PERCENT REDUCTION CPU TIME |
| [illegible] | 0.75 | 1407.52 | 153 | 1482.26 | 15 | 5.31% | 90.19% |
| [illegible] | 0.75 | 1580.84 | 68 | 1616.62 | 19 | 2.26% | 71.21% |
| 3 | 0.75 | 1691.08 | 105 | 1706.71 | 12 | 0.92% | 88.57% |
| 4 | 0.75 | 1647.82 | 98 | 1614.96 | 1[illegible] | -1.99% | 88.77% |
| 5 | 0.75 | 1424.11 | 649 | 1471.63 | 13 | 3.33% | 97.99% |
| 4 | 0.80 | 1522.99 | 53 | 1547.01 | 13 | 1.57% | 18.87% |
| 7 | 0.80 | 1667.08 | [illegible]3 | 1712.05 | 18 | 2.69% | 78.31% |
| 8 | 0.80 | 1778.78 | 163 | 1779.46 | 16 | 0.04% | 90.18% |
| 3 | 0.80 | 1714.34 | 68 | 1735.48 | 12 | 1.23% | 82.35% |
| 10 | 0.80 | 1644.33 | 769 | 1623.72 | 702 | -1.25% | 8.71% |
| 11 | 0.85 | 1754.69 | 164 | 1832.86 | 12 | 4.45% | 92.68% |
| 12 | 0.85 | 1769.24 | 245 | 1847.24 | 17 | 4.41% | 93.06% |
| 13 | 0.85 | 1788.64 | 302 | 1831.39 | 21 | 2.39% | 93.05% |
| 1[illegible] | 0.85 | 1675.65 | 1816 | 1726.15 | 869 | 3.01% | 52.15% |
| 15 | 0.85 | 1685.62 | 274 | 1642.88 | 503 | -2.53% | -83.58% |

TABLE 6. RESULTS OF ACCELERATION PROCEDURE (CONTINUED)

| | | STANDARD METHOD | | TWO PHASE METHOD | | | |
|---|---|---|---|---|---|---|---|
| PROBLEM | PROBABILITY INITIATIVE INCLUDED | BENEFIT VALUE | CPU TIME (sec) | BENEFIT VALUE | CPU TIME (sec) | DIFFERENCE BENEFIT VALUE | PERCENT REDUCTION CPU TIME |
| 16 | 0.90 | 1884.35 | 1000 | 1886.69 | 52 | 0.12% | 95.25% |
| 17 | 0.90 | 1797.75 | 348 | 1835.44 | 194 | 2.09% | 44.25% |
| 16 | 0.90 | 1912.38 | 1134 | 1851.92 | 44 | -3.16% | 96.12% |
| 16 | 0.90 | 1970.42 | 99 | 2006.14 | 11 | 1.81% | 88.88% |
| 20 | 0.90 | 1865.92 | 1583 | 1803.18 | 12 | -3.36% | 99.24% |
| 24 | 0.95 | 2007.99 | 1000 | 1976.05 | 70 | -1.59% | 93.00% |
| 22 | 0.95 | 1968.72 | 124 | 1913.29 | 12 | -2.82% | 90.32% |
| 23 | 0.95 | 1849.76 | 110 | 1902.43 | 21 | 2.84% | 80.91% |
| 24 | 0.95 | 2017.58 | 170 | 2012.67 | 106 | -0.24% | 37.65% |
| 25 | 0.95 | 2022.26 | 1321 | 1950.96 | 99 | -3.33% | 96.67% |
| AVERAGE | | | 479.68 | | 113.96 | 0.73% | 71.40% |

A comparison of the two methods reveals that both methods produce comparable results with respect to the total benefit value of the initiatives selected. However, the two phase approach was able to produce a good integer solution significantly faster than the standard approach. In fact, Table 6 shows that our two phase method reduces the cpu time by an average of 71%. Thus, the two phase method enhances the ability of the planner to conduct rapid "What If" analysis with the OPIS model.

## D. SELECTING PENALTY VALUE

In addition to simply allocating funding for a selected set of initiatives, an important underlying goal during the initiative selection process is the ability to justify the proposed allocation of resources to higher agencies. Consequently, if a moderately large percentage of resources is left unallocated, then it may give the false impression that the available budget level is too high. To ensure that the model produces a solution that allocates as high a percentage of the budget as possible, a penalty is assessed for deviations below the budget limit, i.e., unallocated dollars. In order to determine a specific value for the penalty term that accomplishes this goal, a series of problems with varying penalty values were examined. Table 7 displays the results of varying the penalty parameter for a given problem.

**TABLE 7. RESULTS OF VARYING PENALTY VALUES**

| PENALTY VALUE | TOTAL AMOUNT UNALLOCATED | TOTAL BENEFIT VALUE |
|---|---|---|
| 0.0 | $5,075,550 | 1933.79 |
| 0.1 | $1,381,860 | 1937.14 |
| 0.2 | $685,320 | 1937.14 |
| 0.3 | $64,070 | 1934.45 |
| 0.4 | $223,380 | 1936.41 |
| 0.5 | $305,810 | 1936.23 |

Figure 1 presents a graphic portrayal of the results listed in Table 7.

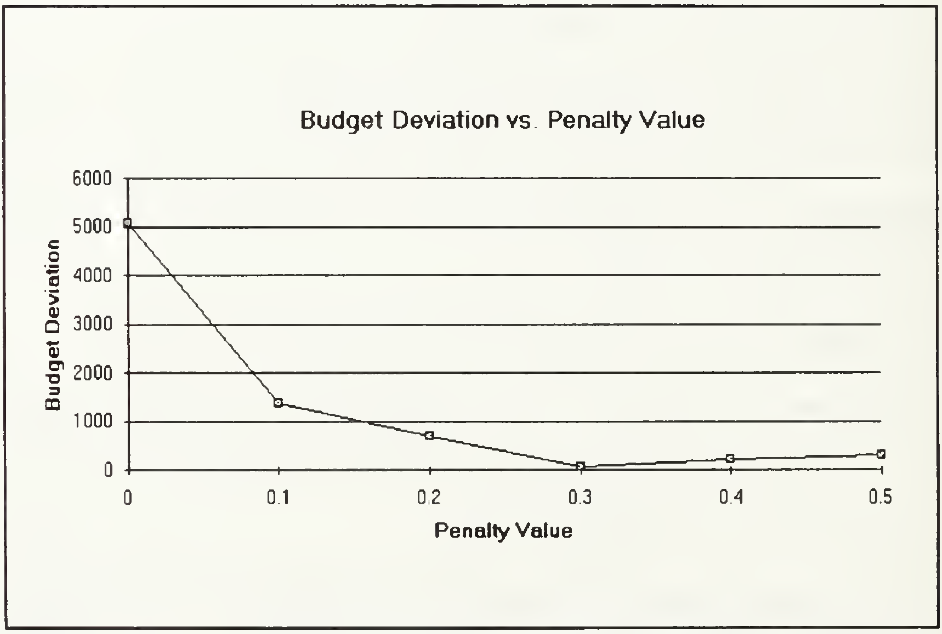


**Figure 1.** Benefit Value Achieved for Varying Penalty Values

Table 7 and Figure 1 demonstrate the effect of changing the value of the penalty parameter on the total amount of dollars

left unallocated. However, the specific penalty value utilized seems to have a relatively small effect on the total benefit value achieved. Therefore, the penalty value providing the smallest amount of unallocated dollars is chosen, i.e., 0.3.

In order to analyze the model's ability to produce solutions that effectively allocate the given level of resources using this penalty value, budget limits ranging from 80% to 110% of the original estimated yearly budget limits were used and the deviation from the yearly budget limit was computed. Table 8 displays the amount of deviation below the budget limit in the first two years of the FYDP, as well as the percentage of the yearly budget that this deviation represents. The process of building a POM is repeated on a bi-annual basis, therefore budget deviations in planning years beyond the second year are not critical since these dollars can be allocated during the next POM formulation.

**TABLE 8. DEVIATIONS BELOW BUDGET LIMITS**

| BUDGET LIMIT % | DEVIATION POM YEAR 1 | DEVIATION POM YEAR 2 | % DEVIATION POM YEAR 1 | % DEVIATION POM YEAR 2 |
|---|---|---|---|---|
| 80% | $20,400 | $94,486 | .005 % | .022 % |
| 85% | $49,300 | $260,305 | .009 % | .047 % |
| 90% | $17,200 | $2,367 | .003 % | .0004 % |
| 95% | $3,101 | $4,376 | .0006 % | .0007 % |
| 100% | $27,000 | $37,434 | .005 % | .007 % |
| 105% | $400,900 | $29,157 | .072 % | .005 % |
| 110% | $34,800 | $29,646 | .006 % | .005 % |

Table 8 shows that the optimal solution produced by the model resulted in a budget deviation of less than 0.1% in planning years one and two for all seven different budget limits. Therefore the model produces acceptable solutions with respect to the amount of the deviation under the budget limit.

## E. SUMMARY REPORTS

The report writing feature of GAMS also creates a series of post-optimization summary reports. After each model run, OPIS generates the following post-optimization summary reports:

- Total Benefit Value Achieved
- Budget Utilization Report
- Initiative Procurement Schedule
- Unfunded Initiatives
- Mission Area Report

A description and an example of each of these reports is discussed in the following sections.

### 1. Total Benefit Value Achieved

This report simply displays the total benefit value of the initiatives selected for procurement by the model. The total benefit value of the selected initiatives provides the decsion maker with a measure for comparing the benefit of different decision packages.

| **TOTAL BENEFIT VALUE REPORT** |
| --- |
| Total Benefit = 2105.82 |

### 2. Budget Utilization Report

This report provides the planner with an overview of how efficiently the budget resources were allocated over the entire FYDP. Table 9 displays the Budget Report for the sample problem data. Recall that OPIS only minimizes the amount of under-utilization in the first two years. This explains the large amount of unallocated dollars in FY98 and FY99.

TABLE 9. BUDGET UTILIZATION REPORT (IN THOUSANDS)

| PLANNING YEAR | BUDGET LIMIT | AMOUNT PURCHASED | AMOUNT UNALLOCATED | PERCENTAGE UNALLOCATED |
|---|---|---|---|---|
| FY94 | $527,198 | $527,043 | $155 | 0.029% |
| FY95 | $548,015 | $547,901 | $113 | 0.021% |
| FY96 | $608,715 | $607,726 | $988 | 0.162% |
| FY97 | $758,027 | $757,554 | $473 | 0.062% |
| FY98 | $881,113 | $877,470 | $3,643 | 0.413% |
| FY99 | $928,507 | $925,076 | $3,431 | 0.369% |

### 3. Initiative Procurement Schedule

This report displays the initiatives selected by the model and denotes the specific year that each initiative will begin receiving funding. Table 10 displays a partial list of the initiatives selected by the model using the sample data set.

TABLE 10. INITIATIVES SELECTED FOR PROCUREMENT

| | STARTING YEAR | | |
|---|---|---|---|
| **INITIATIVE** | **FY94** | **FY95** | **FY96** |
| AN/TRC-170 | | X | |
| GPS-S | X | | |
| AN/PSC-3 U | | X | |
| IAS SUITES | | X | |
| NBC HAZ | X | | |
| T ELEC KEY | | X | |
| SWITCH UG | | | X |
| FUEL DEL | X | | |
| MLRS | | X | |
| LAV SIGHTS | X | | |

### 4. Unfunded Initiatives Report

This report simply displays the initiatives that were not selected by the model. This list can be used as a quick reference by the planner to highlight certain specific initiatives that will not be funded. Table 11 provides a partial list of those initiative not selected for procurement by the model using the sample data set.

**TABLE 11. INITIATIVES NOT SELECTED**

| INITIATIVE | FUNDING STATUS |
|---|---|
| ATACC + 3 | UNFUNDED |
| A/C SMV-36 | UNFUNDED |
| NDI RADAR | UNFUNDED |
| RDR ECCM A | UNFUNDED |
| HAWK LOADER | UNFUNDED |
| SMART - T | UNFUNDED |
| VXI PIP | UNFUNDED |
| AAWS - M | UNFUNDED |
| TANK CR TR | UNFUNDED |
| LAV-105 | UNFUNDED |

### 5. Mission Area Report

This report provides the planner with a breakdown of the funding allocation with respect to each mission area. The planners can use this report to get a more detailed description of the distribution of resources among each mission area and determine if any area was overlooked or is

not receiving a desired level of funding. Table 12 displays the funding allocation distribution for six of the 27 mission areas considered in the sample data set.

**TABLE 12. FUNDING ALLOCATION BY MISSION AREA**

| MISSION AREA | AMOUNT REQUESTED | AMOUNT ALLOCATED | PERCENTAGE TOTAL COST | PERCENTAGE TOTAL BENEFIT |
|---|---:|---:|---:|---:|
| LAV | $777,522 | $181,591 | 4.28% | 4.70% |
| ARTILLERY | $555,459 | $519,315 | 12.24% | 11.07% |
| ARMOR | $1,061,684 | $2,992 | 0.07% | 0.19% |
| AAV/AAA | $933,528 | $588,474 | 13.87% | 0.19% |
| ENGINEER | $358,343 | $280,162 | 6.60% | 2.55% |
| NBC | $1,038,149 | $64,474 | 1.52% | 2.45% |

Together these reports provide the decision maker with the ability to analyze the effects of changes to the input parameters and assist them in determining the mix of initiatives to procure that provides the greatest overall benefit to the Marine Corps.

# CHAPTER V. APPLICATIONS

This chapter highlights potential appications of OPIS. In the previous section it is demonstrated that OPIS serves as a tool to *guide* the planners in the initiative selection process. Here, the term "guide" is chosen to emphasize the belief that mathematical programming models should not be used as an instrument that makes decisions for humans. In particular, results generated from OPIS should not be implemented directly without consulting the decision makers in charge. Throughout this thesis, it is never claimed that OPIS includes or considers every factor present in the process of selecting program initiatives for the Marine Corps. Rather, it is believed that the consulting process typically leads to further questions concerning both the data and the model itself. The subsections below describe some of these questions and illustrate how they can be addressed by OPIS.

## A. CHANGES IN THE BUDGET LIMITS

The current downsizing of the U.S. military and associated cuts in the overall defense budget creates a great deal of instability with regard to the level of financial resources available to all branches of the military. Consequently, Marine Corps planners must be able to quickly determine the effects of changes to the annual budget limits. To examine

the effects of these changes, the budget limits for every year in the planning cycle were varied from 80% to 110% of the original limits. The resulting total benefit values from OPIS are displayed in Table 13.

**TABLE 13. CHANGES IN BUDGET LIMITS**

| % BUDGET LIMIT | BENEFIT VALUE | CHANGE |
|---|---|---|
| 90% | 1969.19 | |
| 95% | 1997.25 | 28.06 |
| 90% | 2005.27 | 8.02 |
| 95% | 2017.24 | 11.97 |
| 100% | 2105.82 | 88.58 |
| 105% | 2123.71 | 17.89 |
| 110% | 2126.58 | 2.87 |

Since the changes in benefit values are not the same for equal amounts of change to the budget limits, the benefit value varies in a nonlinear manner with the size of the budget limits as shown in Figure 2.

In particular, the graph in Figure 2 clearly shows that the impact of a 5% decrease from 100% of the original budget limit (i.e., from 100% to 95%) is much larger than those at 110% and 95%. This implies that an effort to decrease the size of the procurement budget from the original level by 5% would have relatively the strongest effect on total benefit. On the other hand, if the budget limit has already been reduced to 95% of the original, then Figure 2 shows that an additional 5% decrease does not affect the benefit value as drastically.

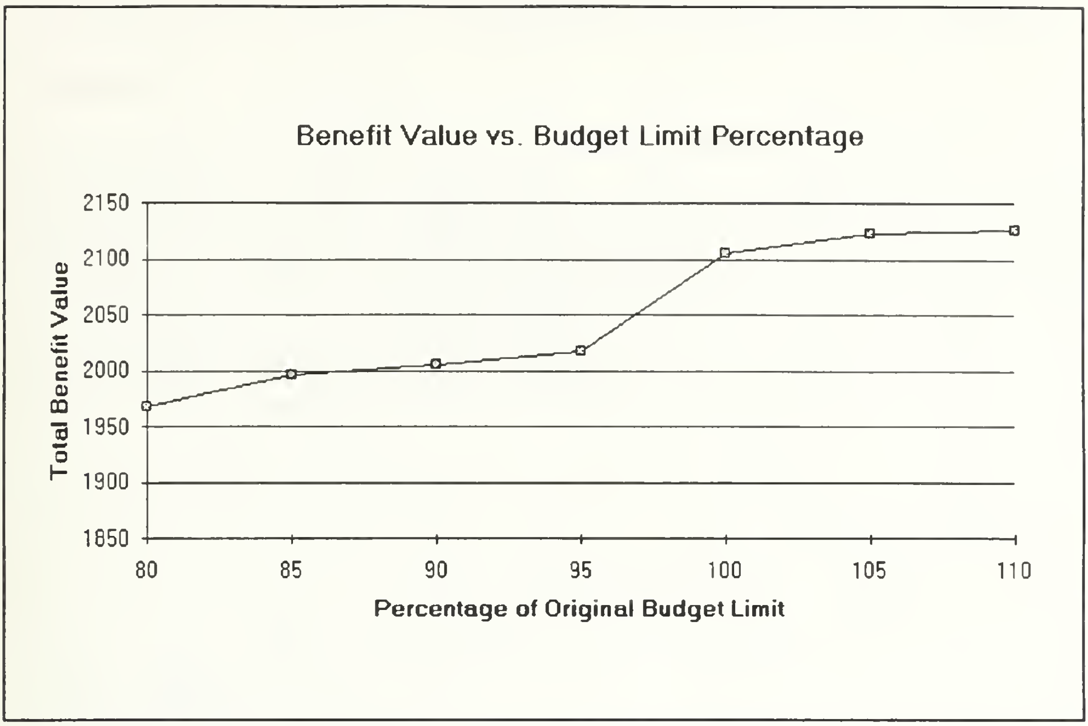


**Figure 2.** Total Benefit Value Achieved for Varying Budget Limits

On the positive side, Table 13 shows that the maximum decrease in the benefit value due to a 5% decrease in the budget limits is 88.85 or 4.21% of the original benefit value of 2105.82. This means that a 5% decrease in the budget translates to at most a 4.21% decrease in benefit value when the initiatives are optimally selected by OPIS. The same conclusion cannot be guaranteed if initiatives are selected in an ad hoc manner. This type of analysis not only enables the planners to examine the effects of varying the budget limit, but it also provides additional justification for receiving a desired budget level.

## B. MANUAL SELECTION OF INITIATIVES

In many situations, optimal solutions produced by mathematical programming models are not usable immediately for they do not take into account many nonquantifiable factors associated with the problem. In the case of initiative selection, these factors include certain aspects of Marine Corps and Joint Operational Plans, strategic and tactical considerations, as well as specific planning guidance received from higher headquarters. These factors are not quantifiable and any attempt to quantify them often leads to controversy, since many believe that they are not quantifiable or they cannot agree on measures for these factors. However, as a tool to support or aid in decision making, OPIS can provide useful "what if" analysis.

To illustrate, consider initiative LAV-105, an initiative not selected by OPIS in Table 11 of Chapter IV. In one scenario, Marine Corps planners may view LAV-105 as being important and may wish to purchase it. To study the effect of this decision, the planners can force OPIS to purchase LAV-105 and analyze the (post-optimality) summary reports. Examples of such analysis are as follows:

1) Forcing OPIS to select LAV-105 reduces the overall benefit from **2105.82** to **2062.78**.

2) Including initiative LAV-105 also causes OPIS to replace the following initiatives (with their respective

benefit values) scheduled for procurement in Table 10, Chapter IV:

5-T-ISO BD (3.660), TAOM ECP (6.323), EXDRONE (1.517),
TRAILER BR (4.339), SAAWC FAC (4.003), AMPH RECON (1.300),
LAV FIRE S (4.122), H WRK PIP (1.093), FLT AIR ST (1.573),
AAV NBC SY (3.643), OPTIC TEST (.920), TSC-120 (2.931)
EST (3.93), ESS GROUND (5.390), CTIF-TACT (2.477),
.45 HANDGU (.533), COM CARGO (.812), HV MG IMP (.635),
AUTO ENTRY (.250), AAV UPGUNN (7.126), M/LOG AIS (.056),
155 LTWT H (3.556),

(**TOTAL BENEFIT = 60.18**),

by the following initiatives:

LAV-105 (3.233), ATACC+3 (13.541), PIPE LAUNC (.207),
M WRK PIP (.080), ANTENNA TW (.057), FAC TR (.028),

(**TOTAL BENEFIT = 17.15**).

Given the results of this "what if" selection of LAV-105, the planners can now determine whether or not the addition of these initiatives outweighs the loss of the above initiatives. If the planners do in fact feel that initiative LAV-105 should be included in the final set of initiatives, then in practice this may mean that LAV-105's benefit was under-valued during the evaluation process described in Chapter II. In either case, having the above information available greatly assists the planners in determining the most beneficial course of action.

## C. SENSITIVITY ANALYSIS

A major factor in scheduling initiatives for procurement in future years is the potential uncertainty of the actual

cost of an initiative. The cost of an individual initiative may increase or decrease depending on a myriad of factors such as emerging technology, manufacturer difficulties, or adjustments as to the number of items, e.g., trucks, to be purchased under the given initiative. The planners and programmers must therefore be capable of analyzing the effects of these changes on the optimal solution.

To illustrate, initiative "MLRS" is among the initiatives selected for procurement in Table 10, Chapter IV. Table 14 displays the results of gradually increasing the procurement cost of initiative MLRS.

**TABLE 14. SENSITIVITY ANALYSIS FOR MLRS**

| TOTAL COST (in $1000) | % INCREASE | MLRS STATUS |
|---|---|---|
| $452,810 | 5% | Selected |
| $474,373 | 10% | Selected |
| $495,935 | 15% | Selected |
| $504,560 | 17% | Selected |
| $508,873 | 18% | Rejected |
| $517,498 | 25% | Rejected |
| $539,060 | 25% | Rejected |
| $560,622 | 30% | Rejected |
| $603,747 | 40% | Rejected |
| $646,872 | 50% | Rejected |

The table shows that MLRS remains selected as long as its cost does not increase beyond 17%. In terms of benefit to the Marine Corps, MLRS can be interpreted as being robust.

Conversely, it would not be a robust initiative if OPIS rejects it as soon as its cost increases by 1% or 2%. In this sense, initiatives which allow for more increase in cost are "better" than those that allow for less.

## CHAPTER VI. CONCLUSIONS

This thesis develops a tool which assists Marine Corps planners in selecting modernization initiatives for implementation. This tool is based on a mixed integer programming (MIP) formulation which offers several enhancements over the planning system currently employed by the Marine Corps planners at the Marine Corps Combat Development Command (MCCDC), Quantico, Virginia. The MIP formulation is designed to simultaneously maximize benefit to the Marine Corps and minimize the budget under-utilization. The proposed tool provides an optimal or near optimal solution, i.e., within 10% of optimality. When combined with the acceleration procedure developed in Chapter IV, it also allows for rapid "what if" analysis, an extremely useful feature for decision making.

The prototype computer system was implemented using commercially available software. The system was tested using an actual data set from the most recent FYDP (POM-94). By request, the prototype system was demonstrated to the planners at MCCDC who were extremely impressed by the potential of the system and desire to utilize it during the POM-96 FYDP.

## A. AREAS FOR FUTURE STUDY

In addition to the results described above, this thesis also identifies the following topics for further research.

### 1. Identifying Initiative Benefit Values

The single most important input parameter to the planning and programming process is the benefit value of each initiative that is determined by the PEG. With this factor in mind, an examination of other prioritization techniques should be conducted. One of the many techniques developed to compare and rank groups of items is the Analytical Hierarchy Process (AHP) suggested by Saaty [Ref. 10].

Due to the inherent flexibility within GAMS, the same model can be run with different data sets. Therefore, this would enable the user to perform a comparison of the various prioritization methods to determine which prioritization method provides benefit values that most accurately reflect the true importance of each initiative.

### 2. Mixed Integer Programming Solvers

The availability and inherent capabilities of commercial integer programming solvers has increased dramatically in the last few years. The usefulness of the model as a decision making aid could be greatly enhanced by a solver that returns optimal solutions faster than the XA solver. The development of a customized algorithmic solver written in a general-purpose language (e.g., Fortran) is also

an option for greatly improving the solve time of the model. However, customized solvers generally are more expensive to procure than commercial solvers, take longer to develop and implement than off-the-shelf software, and are not as easily maintained and updated.

### 3. Incorporate Uncertainty Factors

Many input parameters for OPIS, e.g., procurement cost of initiatives and budget limits in future years, contain a certain degree of uncertainty. Moreover, some modernization initiatives involve or depend on technology not yet fully developed. Therefore, there are additional uncertainties associated with the stated benefit of each initiative. If the required technology does not fully materialize, then the benefit of initiatives requiring that technology may decrease or even be zero. On the other hand, the benefit may remain the same or even increase if the required technology turns out to be better than expected. In any case, optimization models which incorporate uncertainties, e.g., stochastic programming, would offer an interesting direction for research.

## APPENDIX A

The OPIS model developed in this thesis consists of three files: (i) GAMS formulation of OPIS, (ii) set definitions file, and (iii) data input file.

### GAMS FORMULATION

```
$TITLE  OPTIMAL PROGRAM INITIATIVE SELECTION (OPIS) MODEL
$OFFUPPER OFFSYMLIST OFFSYMXREF
*-------------------------------------------------------------*
$ONTEXT

    OPIS is a mixed integer programming model designed to
assist Marine Corps planners in selecting the set of
modernization programs that provide the most benefit to the
Marine Corps.

    Formulated July 92 - October 92 by:

        Analyst:  Mark A. Adams, Captain, USMC
        Advisor:  Dr. Siriphong Lawphongpanich, Code OR/Lp
                  Naval Postgraduate School
                  Monterey, CA 93943-5000

$OFFTEXT
*-------------------------------------------------------------*

OPTIONS
  INTEGER1    = 6,
  LIMCOL      = 0,
  LIMROW      = 0,
  SOLPRINT    = OFF,
  DECIMALS    = 3,
  RESLIM      = 100000,
  ITERLIM     = 70000,
  OPTCR       = 0.20,
  SEED        = 3141;

*------ SET DEFINITIONS AND DATA ----------------------------*

SETS
   I          program objective memorandum initiatives
   S          allowable yearly schedules
```

```
   MISSAREA  Marine Corps mission areas for planning and
             programming
   LABELS    headings for table containing initiative data
   PR        counter used for assigning costs to initiatives
             under various schedules
   NUM       index used for logical constraints

ALIAS (I,J)

SCALARS
   MAXBUY     maximum number of schedules that can be
              purchased / 1 /
   BASEYR     reference year for determining the start
              year of required purchases / 93 /
   PENDEV     Penalty for deviation from budget limit
              / 0.3 /

$INCLUDE POM2 SET A
$INCLUDE POM2 DATA A

*------ MODEL ---------------------------------------------*

BINARY VARIABLES
   X(I,S)        binary variable for initiative i under
                 schedule s  'purchase or not purchased'
   Z(NUM)       binary variable used for logical constraints;

X.FX(I,S)$(DATA(I,'STYR'))= 1$((DATA(I,'STYR') - BASEYR)
                                              EQ ORD(S) ) ;
X.FX(I,S)$((ORD(S) GT 1)AND((SUM(Y$(ORD(Y) LE 2),
                                      DATA(I,Y))) EQ 0))=0;

VARIABLE
   TOTBEN        total benefit value of initiatives purchased
                 minus penalty for unallocated dollars

POSITIVE VARIABLES
   DEV(Y)        deviation from budget limit in year y ;

EQUATIONS
   BENEFIT       total benefit of initiatives purchased minus
                 penalty for unallocated dollars
   BUDGET(Y)     observe budget limits including deviations
   ONESCHED(I)  ensure at most one schedule purchased for each
                 intiative
   ONESCH2(I)   ensure at most one schedule purchased for each
                 initiative in two phase model
   COMPETE(NUM) purchase at most one initiative for each
                 group of competing initiatives
   CONDITION(I) ensure dependent initiatives are purchased as
                 required
```

```
   IFTHEN1(NUM)   pair of constraints to ensure complementary
   IFTHEN2(NUM,I) initiatives are purchased as required ;

* maximize
     BENEFIT..  TOTBEN =E= SUM((I,S),DATA(I,'BV')*X(I,S)) -
                          PENDEV*SUM(Y$(ORD(Y) LE 2),DEV(Y));


* subject to
     BUDGET(Y)..   SUM((I,S), COST(I,S,Y)*X(I,S)) +
                                        DEV(Y)=E= BL(Y) ;

     ONESCHED(I)..      SUM(S, X(I,S)) =L= MAXBUY ;

     ONESCH2(I)$(SUM(S, X.LO(I,S)) EQ 0)..
                        SUM(S,X(I,S)) =L= MAXBUY ;

     COMPARABLE(NUM).. SUM((I,S)$ONLYONE(NUM,I), X(I,S))
                                             =L= MAXBUY ;

     CONDITION(I)..    SUM(J,DEPENDENT(I,J))*SUM(S,X(I,S)) -
                        SUM(J,DEPENDENT(I,J)*SUM(S,X(J,S)))
                                                    =G=0;

     IFTHEN1(NUM)..     SUM((I,S)$MUSTBUY(NUM,I),X(I,S)) =G=
                         SUM(I,MUSTBUY(NUM,I))*Z(NUM)  ;

     IFTHEN2(NUM,I)$MUSTBUY(NUM,I)..
                        SUM(S,X(I,S)) =L= Z(NUM);


MODEL POM1 /BENEFIT, BUDGET, ONESCHED, COMPARABLE, CONDITION,
            IFTHEN1, IFTHEN2 / ;

MODEL POM2 /BENEFIT, BUDGET, ONESCH2, COMPARABLE, CONDITION,
            IFTHEN1, IFTHEN2   /  ;

*--------BEGIN TWO PHASE METHOD-----------------------------*

SOLVE POM1 USING RMIP MAXIMIZING TOTBEN ;

X.FX(I,S)$((X.L(I,"SCHED94") EQ 1) OR (X.L(I,"SCHED95") EQ 1)
                      OR (X.L(I,"SCHED96") EQ 1)) = X.L(I,S);


SOLVE POM2 USING MIP MAXIMIZING TOTBEN  ;

*---------REPORTS-------------------------------------------*

DISPLAY TOTBEN.L;
```

```
DISPLAY X.L;


PARAMETER POMBEN;  Total Benefit Value of Selected Initiatives

POMBEN=SUM((I,S),DATA(I,'BV')*X.L(I,S));
DISPLAY POMBEN;

PARAMETER REPORT1(Y,*);     Budget Utilization Report

REPORT1(Y,"BUDGTLIMIT")  = BL(Y) ;
REPORT1(Y,"PURCHASED")   = SUM((I,S), X.L(I,S)*COST(I,S,Y)) ;
REPORT1(Y,"DIFFERENCE")     =    BL(Y)    -    SUM((I,S),
X.L(I,S)*COST(I,S,Y)) ;
REPORT1(Y,"%DEVIATION")  = ((BL(Y) - SUM((I,S),
                         X.L(I,S)*COST(I,S,Y)))*100)/BL(Y)  ;
DISPLAY REPORT1 ;

PARAMETER BUYPROGRAM(*,*);   Initiative Procurement Schedule

BUYPROGRAM(I,Y)         = SUM(S, X.L(I,S)*COST(I,S,Y)) ;
BUYPROGRAM("TOTAL",Y)  = SUM((I,S), X.L(I,S)*COST(I,S,Y)) ;

OPTIONS BUYPROGRAM:0:1:1; DISPLAY BUYPROGRAM ;

PARAMETER MSNAREA(*,*);    Mission Area Report

MSNAREA(MISSAREA,'TOTREQUEST') = SUM((I,Y)$(DATA(I,'MA') EQ
                                   ORD(MISSAREA)),DATA(I,Y));
MSNAREA(MISSAREA,'TOT SPENT')  = SUM((I,S,Y)$(DATA(I,'MA') EQ
                         ORD(MISSAREA)),X.L(I,S)*COST(I,S,Y));
MSNAREA(MISSAREA,'% TOT COST')=SUM((I,S,Y)$(DATA(I,'MA') EQ
                    ORD(MISSAREA)),X.L(I,S)*COST(I,S,Y))*100/
                         SUM((I,S,Y), X.L(I,S)*COST(I,S,Y));
MSNAREA(MISSAREA,'% TOT BENF')=SUM((I,S)$(DATA(I,'MA') EQ
                  ORD(MISSAREA)),X.L(I,S)*DATA(I,'BV'))*100/
                         SUM((I,S), DATA(I,'BV')*X.L(I,S));

OPTIONS MSNAREA:2:1:1; DISPLAY MSNAREA ;
```

**GAMS SET DEFINITIONS FILE**

```
SETS

   S  schedule      / SCHED94*SCHED96 /

   I  initiative    /'AN/TRC-170', 'GPS-S', 'AN/PSC-3 U',
                 'IAS SUITES', 'NBC HAZ','T ELEC KEY',
                 'SWITCH UG',  'FUEL DEL', 'FB OPTIC D',
                 'AN/PSC3 RE', 'AN/TSQ-130', 'M&RA ADP',
                 'ELECT TMDE', 'AN/MRC-142', 'UHF RELAY',
                 'IDASC IMP',  'PLT CMD PT','PLRS ENHAN',
                 'COMSEC CAB', 'SHOP SET', 'ENVIRON EQ',
                 'GPS IU', 'MOB ROAD B', 'TRSS PHS V',
                 'CPT SWITCH', 'EDI MODELS', 'UHF SATCOM',
                 'LAV FUEL F', 'MHE', 'TSCM PIP','LEWDD',
                 'MAGTF SIDS', 'CHEM AER D','BRIDGE SCS',
                 'MAGROLLS', 'REMOTE SWT', 'MCAIMS', 'MACS',
                 'RETS', 'INTEL ANAL', 'PWR SUPPLY', 'RDR A/C',
                 'LVS FUEL/C', 'AAV MPLOW', 'FSTER SWTH',
                 'LAV SIGHTS', 'MAFATDS', 'WHOUSE MOD', 'RRC',
                 'TOW SIGHTS', 'AN/PSS12', 'CONT TEST',
                 'IAS WKSTAT', 'CONFLICT S','MSC-63A PI',
                 'RIVERINE C', 'RS LAN','AMAL LAB E',
                 'TBFDS CH53', 'MIDAS', 'GPS HH REC',
                 'INF AIM LT', 'LAV ANTITK', 'LVS TRANSP',
                 'DIGIT TECH', 'MPF REF CN', 'RIPP F/D7G',
                 'WNCH F/D7G', 'MMS','PDLS','THER IMAGI',
                 'D7G TP PIP', 'GEN 100KW', 'RDR CORREL',
                 'LSD SWT RP', 'CIEP', 'MK18 CONTA',
                 'AMAL OR EQ', 'IFASC PIP', 'DIG CIRCUI',
                 'AAV FIRE S', '05 RDR RCS','TACT PETRO',
                 'TRSS PIP',   'TERPES PIP','DIVE SFT E',
                 'AAV MOD KT', '7.62 MG IM','IND MKS TR',
                 'SPEED', 'AMAL X-RAY', 'JSIPS',
                 'HAWK MOB L', 'MOTORCYCLE', 'RIBBON BDG',
                 'FASCAM', 'GAP CROSSI', 'AMCS',
                 'EL OPT UG',  'JTIDS INTG', 'GRD MARK',
                 'PORT HELI',  'SOCV', 'NBC RECONN',
                 'OFF RSUP D', 'FOCS', 'OPT IMAG S',
                 'AN/MRC/142', 'LAV MD RAM', 'RANGEFINDE',
                 'DBAR F/D7G', 'MLRS', 'M4 CARBINE','CMV',
                 'IMAGE INTE', 'HW RPL LAN', 'MEWSS',
                 'TOW MOD KT', 'MOUT TARGE', 'LVS CARGO',
                 'HOSE REEL',  'A/C SMV-18', 'IMP TAS BL',
                 'EUC', 'EXCAVT ATT', 'MF LASER P',
                 'CALIBR PIP', 'ACE', 'SURVEY SET',
                 'M101A1 REP', 'LAV FIRING', 'LVS INFLAT',
                 '5 T ISO BD', 'WANG REPLA', 'APOBS',
                 'ATACC + 3',  'LAV TURRET', 'SCT',
                 'AAV PROP S', 'LASER WR V', 'TAOM ECP',
```

```
                    'EXDRONE', 'TRAILER BR', 'UNM GRD VH',
                    'SAAWC FAC', 'ENH ROWPU', 'AMPH RECON',
                    'LAV FIRE S', '7.62 MARKS', 'NIBERS',
                    'H WRK PIP', '5 T LIFTIN', 'MTWS',
                    'FLT AIR ST', 'AAV SIGHTS', 'RM NEUTRAL',
                    'AAV NBC SY', 'OPTIC TEST', 'TSC - 120',
                    '5-TON SLEP', 'EST', 'ESS GROUND',
                    'ROLLER COM', 'CTIF-TACT', 'A/C SMV-36',
                    '.45 HANDGU', 'D7G MB PIP','MILES',
                    'COM CARGO',  'HV MG IMP', 'NDI RADAR',
                    'RDR ECCM A', 'AUTO ENTRY','OPT DISK S',
                    'HAWK LOADE', 'SMART - T', 'VXI PIP',
                    'AAWS-M', 'AAV UPGUNN', 'TANK CR TR', 'MSSS-1',
                    'SRAW', 'MSC-63 DS', 'M88A1 RECO', 'M/LOG AIS',
                    'TAOM TR', 'AAV CR TR', 'MRT', 'ELEC SENSR',
                    'AV EQ', 'RADIO TRUN', 'CTIS', 'PIPE LAUNC',
                    'TCO', 'GP RADIO R', 'MIPS/MILOG', 'PMS',
                    'CONTR LIFT', '1413 PLRSD', 'LAV-E',
                    'SMAW MOD 1', 'DEMNS', 'AIRFLD TR', 'LAV-AD',
                    '155 LTWT H', 'CALS', 'M WRK PIP',
                    'WELDER TRL', 'M198 HOWIT', 'DMS WKSTAT',
                    'AUTO ID TC', 'NBC  MODERN', 'DTSFO',
                    'LAV-105', 'SANDY RUN', 'RAAM', 'M1A1 BLOCK',
                    'ANTENNA TW', 'TOW 2B MIS', 'UMPT', 'FAC TR',
                    'TOW 2A MIS', 'PORT TECHC', 'AN/TRC/170',
                    'TAMP', 'SINCGARS', 'MINI HH RA', 'RDR DISPLA',
                    'AUTO KD RG', 'WAR GAMES', 'HW RPL MWR',
                    'HW REP EQ',  'SW RPL' /

LABELS / MA, STYR, BV, 94*99    /

Y(LABELS)  year   / 94*99 /

PR     counter    / 1*6   /

NUM               / 1*50  /

MISSAREA          / 'LAV'
                    'ARTILLERY'
                    'ARMOR'
                    'AAV/AAA'
                    'ENGINEER'
                    'NBC'
                    'RECON'
                    'TDEW'
                    'INF/ANTIAR'
                    'NED'
                    'AIR C3'
                    'COMM'
                    'COMPUTERS'
                    'INTELL'
```

```
'MOTOR T'
'ENGINEER2'
'LOGISTICS'
'UAV'
'ASSLT SUP'
'AIR DEF'
'TRNG&EDUC'
'MINE CTRMR'
'ISWG'
'BASE COMM'
'PHYS SEC'
'OTHER(I&L)'
'PST'                    / ;
```

## GAMS DATA FILE

TABLE DATA(I,LABELS)  input data for each initiative

| | MA | STYR | BV | 94 | 95 | 96 | 97 | 98 | 99 |
|---|---|---|---|---|---|---|---|---|---|
| 'AN/TRC-170' | 12 | 95 | 83.077 | 581 | 68 | 0 | 0 | 0 | 0 |
| 'GPS-S' | 2 | 0 | 58.217 | 2283 | 0 | 0 | 0 | 0 | 0 |
| 'AN/PSC-3 U' | 12 | 0 | 89.768 | 0 | 1872 | 3008 | 274 | 264 | 81 |
| 'IAS SUITES' | 14 | 0 | 42.140 | 1474 | 105 | 238 | 105 | 247 | 105 |
| 'NBC HAZ' | 6 | 0 | 23.663 | 1010 | 950 | 13 | 5 | 9 | 9 |
| 'T ELEC KEY' | 25 | 0 | 5.529 | 95 | 64 | 320 | 30 | 0 | 0 |
| 'SWITCH UG' | 25 | 0 | 9.114 | 300 | 220 | 110 | 60 | 360 | 60 |
| 'FUEL DEL' | 17 | 0 | 16.501 | 0 | 0 | 2113 | 8 | 198 | 8 |
| 'FB OPTIC D' | 25 | 0 | 9.114 | 60 | 90 | 204 | 170 | 170 | 700 |
| 'AN/PSC3 RE' | 12 | 0 | 33.386 | 2257 | 2442 | 201 | 91 | 70 | 70 |
| 'IDASC IMP' | 11 | 0 | 79.208 | 3462 | 3402 | 3761 | 3203 | 355 | 367 |
| 'AN/MRC-142' | 12 | 0 | 55.976 | 11770 | 0 | 0 | 0 | 0 | 0 |
| 'AN/TSQ-130' | 14 | 0 | 9.278 | 1738 | 72 | 36 | 36 | 36 | 36 |
| 'UHF RELAY' | 12 | 0 | 12.961 | 1706 | 234 | 105 | 86 | 86 | 86 |
| 'M&RA ADP' | 24 | 0 | 4.005 | 287 | 302 | 216 | 51 | 53 | 55 |
| 'ELECT TMDE' | 28 | 0 | 11.000 | 676 | 680 | 515 | 349 | 351 | 184 |
| 'COMSEC CAB' | 12 | 0 | 30.907 | 3305 | 1317 | 907 | 786 | 662 | 663 |
| 'SHOP SET' | 16 | 0 | 2.466 | 0 | 660 | 5 | 5 | 5 | 5 |
| 'ENVIRON EQ' | 27 | 0 | 11.500 | 610 | 664 | 633 | 696 | 644 | 713 |
| 'GPS IU' | 12 | 0 | 10.796 | 2788 | 150 | 95 | 140 | 140 | 185 |
| 'MOB ROAD B' | 5 | 0 | .682 | 52 | 50 | 58 | 58 | 26 | 33 |
| 'TRSS PHS V' | 14 | 0 | 36.752 | 9577 | 2100 | 1450 | 650 | 700 | 700 |
| 'CPT SWITCH' | 25 | 0 | 12.700 | 6000 | 0 | 0 | 0 | 0 | 0 |
| 'EDI MODELS' | 24 | 0 | 1.256 | 107 | 107 | 107 | 107 | 107 | 107 |
| 'UHF SATCOM' | 12 | 0 | 4.403 | 918 | 973 | 155 | 59 | 43 | 43 |
| 'LAV FUEL F' | 17 | 0 | 3.200 | 0 | 0 | 1108 | 273 | 18 | 18 |
| 'MHE' | 27 | 0 | 4.625 | 1240 | 620 | 620 | 0 | 0 | 0 |
| 'TSCM PIP' | 14 | 0 | 1.987 | 539 | 21 | 21 | 21 | 539 | 21 |
| 'LEWDD' | 21 | 0 | 3.983 | 1359 | 1002 | 0 | 0 | 0 | 0 |
| 'MAGTF SIDS' | 14 | 0 | 47.528 | 5186 | 6568 | 8553 | 2875 | 3029 | 1588 |

| | MA | STYR | BV | 94 | 95 | 96 | 97 | 98 | 99 |
|---|---|---|---|---|---|---|---|---|---|
| 'CHEM AER D' | 6 | 0 | 11.632 | 0 | 0 | 0 | 0 | 3805 | 3393 |
| 'BRIDGE SCS' | 3 | 0 | 4.047 | 0 | 2794 | 16 | 0 | 0 | 0 |
| 'MAG ROLL S' | 23 | 0 | 3.779 | 0 | 0 | 1115 | 701 | 212 | 107 |
| 'REMOTE SWT' | 25 | 0 | .150 | 0 | 54 | 0 | 54 | 0 | 0 |
| 'MCAIMS' | 24 | 0 | 1.168 | 848 | 0 | 0 | 0 | 0 | 0 |
| 'MACS' | 23 | 0 | 11.097 | 0 | 0 | 3688 | 2648 | 299 | 175 |
| 'RETS' | 22 | 0 | 81.000 | 15274 | 10365 | 7718 | 5954 | 2347 | 2342 |
| 'INTEL ANAL' | 14 | 0 | 92.937 | 36990 | 16723 | 1705 | 2297 | 1651 | 1473 |
| 'PWR SUPPLY' | 28 | 0 | 5.000 | 869 | 931 | 962 | 967 | 6 | 0 |
| 'RDR A/C' | 11 | 0 | .527 | 400 | 0 | 0 | 0 | 0 | 0 |
| 'LVS FUEL/C' | 16 | 0 | 35.475 | 14012 | 13787 | 100 | 100 | 100 | 100 |
| 'AAV MPLOW' | 23 | 0 | 20.513 | 0 | 0 | 8534 | 5983 | 396 | 421 |
| 'FSTER SWTH' | 25 | 0 | 7.321 | 6000 | 0 | 0 | 0 | 0 | 0 |
| 'LAV SIGHTS' | 1 | 0 | 80.290 | 34510 | 34695 | 137 | 4 | 3 | 3 |
| 'PLT CMD PT' | 21 | 0 | 47.132 | 0 | 18038 | 14435 | 11820 | 10 | 10 |
| 'MAFATDS' | 2 | 0 | 59.286 | 15862 | 16868 | 11860 | 2989 | 3132 | 3270 |
| 'WHOUSE MOD' | 27 | 0 | 2.900 | 1095 | 1095 | 195 | 195 | 195 | 195 |
| 'RRC' | 7 | 0 | 6.559 | 1863 | 2809 | 3150 | 0 | 0 | 0 |
| 'TOW SIGHTS' | 9 | 0 | 1.423 | 954 | 388 | 376 | 0 | 0 | 0 |
| 'PLRS ENHAN' | 12 | 0 | 9.043 | 0 | 4936 | 795 | 316 | 324 | 324 |
| 'AN/PSS12' | 23 | 0 | 1.161 | 817 | 495 | 78 | 8 | 12 | 12 |
| 'CONT TEST' | 12 | 0 | 4.403 | 0 | 2842 | 2753 | 140 | 20 | 0 |
| 'IAS WKSTAT' | 14 | 0 | 8.063 | 5684 | 400 | 742 | 400 | 570 | 400 |
| 'CONFLICT S' | 24 | 0 | 2.595 | 580 | 810 | 525 | 505 | 525 | 580 |
| 'MSC-63A PI' | 12 | 0 | 2.509 | 1625 | 1525 | 40 | 40 | 40 | 40 |
| 'RIVERINE C' | 7 | 0 | 3.748 | 4338 | 867 | 0 | 0 | 0 | 0 |
| 'RS LAN' | 24 | 0 | 1.256 | 1763 | 0 | 0 | 0 | 0 | 0 |
| 'AMAL LAB E' | 18 | 0 | 2.466 | 3476 | 0 | 0 | 0 | 0 | 0 |
| 'TBFDS CH53' | 17 | 0 | 3.928 | 5115 | 265 | 250 | 0 | 0 | 0 |
| 'MIDAS' | 24 | 0 | 2.252 | 1003 | 610 | 624 | 638 | 423 | 423 |
| 'GPS HH REC' | 12 | 0 | 30.631 | 43835 | 1054 | 1054 | 1054 | 1054 | 1054 |
| 'INF AIM LT' | 7 | 0 | 11.949 | 12593 | 8113 | 0 | 0 | 0 | 0 |
| 'LAV ANTITK' | 1 | 0 | 4.213 | 0 | 0 | 0 | 0 | 7277 | 34 |
| 'LVS TRANSP' | 16 | 0 | 18.055 | 28431 | 1188 | 490 | 473 | 473 | 473 |
| 'DIGIT TECH' | 12 | 0 | 13.750 | 0 | 0 | 6115 | 10815 | 5225 | 2175 |

| | MA | STYR | BV | 94 | 95 | 96 | 97 | 98 | 99 |
|---|---|---|---|---|---|---|---|---|---|
| 'MPF REF CN' | 27 | 0 | 7.500 | 2700 | 2700 | 2700 | 2700 | 2484 | 0 |
| 'RIPP F/D7G' | 17 | 0 | .444 | 787 | 0 | 0 | 0 | 0 | 0 |
| 'WNCH F/D7G' | 17 | 0 | .444 | 793 | 0 | 0 | 0 | 0 | 0 |
| 'MMS' | 2 | 0 | 11.990 | 8355 | 5843 | 407 | 407 | 407 | 407 |
| 'PDLS' | 11 | 0 | 13.498 | 11942 | 12682 | 105 | 105 | 105 | 105 |
| 'THER IMAGI' | 10 | 0 | 28.019 | 0 | 0 | 6986 | 14509 | 14733 | 14096 |
| 'D7G TP PIP' | 17 | 0 | 3.397 | 5100 | 297 | 308 | 279 | 279 | 189 |
| 'GEN 100KW' | 17 | 0 | 3.198 | 3120 | 3160 | 0 | 0 | 0 | 0 |
| 'RDR CORREL' | 11 | 0 | 1.103 | 1200 | 1000 | 0 | 0 | 0 | 0 |
| 'LSD SWT RP' | 25 | 0 | 1.943 | 0 | 0 | 4000 | 0 | 0 | 0 |
| 'CIEP' | 14 | 0 | 1.015 | 402 | 11 | 11 | 1688 | 12 | 12 |
| 'MK18 CONTA' | 16 | 0 | 13.846 | 14617 | 14616 | 0 | 0 | 0 | 0 |
| 'AMAL OR EQ' | 18 | 0 | 1.644 | 3645 | 0 | 0 | 0 | 0 | 0 |
| 'IFASC PIP' | 13 | 0 | 4.196 | 7772 | 168 | 252 | 432 | 432 | 432 |
| 'DIG CIRCUI' | 12 | 0 | 9.043 | 8030 | 12077 | 0 | 200 | 200 | 200 |
| 'AAV FIRE S' | 4 | 0 | 3.664 | 3 | 2131 | 2357 | 2125 | 233 | 328 |
| '05 RDR RCS' | 11 | 0 | 13.941 | 2420 | 13340 | 12170 | 4910 | 0 | 0 |
| 'TACT PETRO' | 17 | 0 | 3.202 | 5925 | 89 | 99 | 99 | 89 | 89 |
| 'TRSS PIP' | 14 | 0 | 4.417 | 0 | 0 | 7925 | 3304 | 0 | 0 |
| 'TERPES PIP' | 14 | 0 | 36.752 | 10298 | 6856 | 6856 | 9448 | 7056 | 6956 |
| 'DIVE SFT E' | 7 | 0 | 1.800 | 779 | 779 | 779 | 779 | 779 | 779 |
| 'AAV MOD KT' | 4 | 0 | 3.098 | 8059 | 0 | 0 | 0 | 0 | 0 |
| '7.62 MG IM' | 9 | 0 | 15.953 | 21004 | 21017 | 0 | 0 | 0 | 0 |
| 'IND MKS TR' | 22 | 0 | 2.466 | 2868 | 2014 | 102 | 102 | 72 | 72 |
| 'SPEED' | 12 | 0 | .948 | 1709 | 200 | 200 | 200 | 200 | 0 |
| 'AMAL X-RAY' | 18 | 0 | 1.479 | 4027 | 0 | 0 | 0 | 0 | 0 |
| 'JSIPS' | 14 | 0 | 38.287 | 1225 | 30564 | 36021 | 30718 | 2154 | 2295 |
| 'HAWK MOB L' | 21 | 0 | 16.839 | 22950 | 20950 | 750 | 750 | 750 | 750 |
| 'MOTORCYCLE' | 16 | 0 | .380 | 0 | 0 | 1099 | 0 | 0 | 0 |
| 'RIBBON BDG' | 17 | 0 | 1.316 | 3900 | 181 | 0 | 0 | 0 | 0 |
| 'FASCAM' | 23 | 0 | 6.551 | 0 | 0 | 11294 | 8106 | 137 | 112 |
| 'GAP CROSSI' | 17 | 0 | 3.699 | 9400 | 1173 | 97 | 83 | 83 | 83 |
| 'AMCS' | 23 | 0 | 1.935 | 0 | 0 | 0 | 0 | 0 | 4923 |
| 'EL OPT UG' | 28 | 0 | 6.100 | 302 | 572 | 6120 | 11704 | 1484 | 25 |
| 'JTIDS INTG' | 11 | 0 | 39.746 | 16697 | 38216 | 37070 | 16627 | 16532 | 4462 |

| | MA | STYR | BV | 94 | 95 | 96 | 97 | 98 | 99 |
|---|---|---|---|---|---|---|---|---|---|
| 'GRD MARK' | 23 | 0 | 3.626 | 3620 | 6620 | 198 | 170 | 165 | 190 |
| 'PORT HELI' | 20 | 0 | 1.775 | 582 | 1178 | 2511 | 1593 | 83 | 70 |
| 'SOCV' | 7 | 0 | 3.803 | 182 | 1709 | 4131 | 4600 | 2450 | 0 |
| 'NBC RECONN' | 6 | 0 | 16.283 | 0 | 0 | 0 | 0 | 30110 | 25170 |
| 'OFF RSUP D' | 7 | 0 | .087 | 53 | 53 | 53 | 52 | 52 | 52 |
| 'FOCS' | 12 | 0 | 13.974 | 0 | 0 | 0 | 7800 | 12580 | 14345 |
| 'OPT IMAG S' | 24 | 0 | 4.000 | 3003 | 2004 | 2004 | 6002 | 2003 | 3 |
| 'AN/MRC/142' | 12 | 0 | 2.469 | 5075 | 4264 | 0 | 0 | 0 | 0 |
| 'LAV MD RAM' | 1 | 0 | 4.164 | 2698 | 2701 | 2904 | 2904 | 2904 | 2904 |
| 'RANGEFINDE' | 10 | 0 | 11.743 | 0 | 497 | 10483 | 10596 | 10944 | 7700 |
| 'DBAR F/D7G' | 17 | 0 | .030 | 122 | 0 | 0 | 0 | 0 | 0 |
| 'MLRS' | 2 | 0 | 100.000 | 96904 | 90695 | 94164 | 89719 | 29210 | 30556 |
| 'M4 CARBINE' | 7 | 0 | 3.769 | 6259 | 1531 | 1338 | 1339 | 1339 | 1940 |
| 'CMV' | 5 | 0 | 20.674 | 0 | 0 | 0 | 0 | 0 | 46274 |
| 'IMAGE INTE' | 7 | 0 | 2.057 | 6514 | 2129 | 62 | 38 | 39 | 41 |
| 'HW RPL LAN' | 24 | 0 | .183 | 277 | 282 | 195 | 45 | 45 | 45 |
| 'MEWSS' | 14 | 0 | 9.764 | 9268 | 9164 | 12957 | 5716 | 1150 | 950 |
| 'TOW MOD KT' | 9 | 0 | 1.423 | 5781 | 675 | 658 | 0 | 0 | 0 |
| 'MOUT TARGE' | 22 | 0 | .948 | 0 | 690 | 455 | 422 | 400 | 400 |
| 'LVS CARGO' | 16 | 0 | .600 | 1771 | 1300 | 31 | 32 | 33 | 34 |
| 'HOSE REEL' | 17 | 0 | 3.675 | 0 | 7383 | 12254 | 98 | 63 | 63 |
| 'A/C SMV-18' | 17 | 0 | .296 | 833 | 861 | 0 | 0 | 0 | 0 |
| 'IMP TAS BL' | 21 | 0 | 2.607 | 5780 | 5765 | 3120 | 320 | 330 | 0 |
| 'EUC' | 24 | 0 | 4.100 | 7394 | 4399 | 3684 | 3681 | 3851 | 4023 |
| 'EXCAVT ATT' | 17 | 0 | .148 | 1035 | 2 | 0 | 0 | 0 | 0 |
| 'MF LASER P' | 24 | 0 | .031 | 91 | 8 | 8 | 91 | 8 | 8 |
| 'CALIBR PIP' | 28 | 0 | 3.500 | 5980 | 6060 | 4645 | 3210 | 3250 | 1795 |
| 'ACE' | 5 | 0 | 22.407 | 61668 | 62105 | 30211 | 384 | 392 | 385 |
| 'SURVEY SET' | 17 | 0 | .237 | 1750 | 6 | 0 | 0 | 0 | 0 |
| 'M101A1 REP' | 16 | 0 | .247 | 1812 | 10 | 10 | 0 | 0 | 0 |
| 'LAV FIRING' | 22 | 0 | .579 | 3862 | 17 | 32 | 32 | 32 | 32 |
| 'LVS INFLAT' | 16 | 0 | 2.739 | 7645 | 6873 | 6872 | 78 | 78 | 78 |
| '5 T ISO BD' | 16 | 0 | 3.660 | 14712 | 14910 | 0 | 0 | 0 | 0 |
| 'WANG REPLA' | 24 | 0 | .172 | 585 | 163 | 163 | 163 | 163 | 163 |
| 'APOBS' | 23 | 0 | 4.334 | 3725 | 8841 | 7383 | 7023 | 7809 | 71 |

| | MA | STYR | BV | 94 | 95 | 96 | 97 | 98 | 99 |
|---|---|---|---|---|---|---|---|---|---|
| 'ATACC + 3' | 11 | 0 | 13.541 | 27496 | 6051 | 4803 | 5215 | 4255 | 4255 |
| 'LAV TURRET' | 1 | 0 | 6.238 | 0 | 0 | 0 | 0 | 0 | 51300 |
| 'SCT' | 12 | 0 | 2.425 | 130 | 2587 | 6895 | 6176 | 820 | 780 |
| 'AAV PROP S' | 4 | 0 | 71.578 | 106 | 15758 | 151058 | 159970 | 159228 | 117974 |
| 'LASER WR V' | 8 | 0 | 5.603 | 0 | 11670 | 15610 | 15055 | 1685 | 2370 |
| 'TAOM ECP' | 11 | 0 | 6.323 | 14910 | 10730 | 7960 | 9250 | 9250 | 3490 |
| 'EXDRONE' | 19 | 0 | 1.517 | 2890 | 5340 | 4235 | 162 | 194 | 127 |
| 'TRAILER BR' | 17 | 0 | 4.339 | 0 | 0 | 0 | 0 | 37157 | 1379 |
| 'UNM GRD VH' | 5 | 0 | 6.018 | 0 | 0 | 0 | 0 | 9331 | 16131 |
| 'SAAWC FAC' | 11 | 0 | 4.003 | 14977 | 19705 | 1000 | 1000 | 1000 | 1000 |
| 'ENH ROWPU' | 17 | 0 | 2.770 | 0 | 0 | 2660 | 12500 | 12432 | 0 |
| 'AMPH RECON' | 7 | 0 | 1.300 | 4899 | 4711 | 3430 | 0 | 0 | 0 |
| 'LAV FIRE S' | 1 | 0 | 4.122 | 0 | 0 | 20871 | 20737 | 83 | 6 |
| '7.62 MARKS' | 7 | 0 | .899 | 0 | 6207 | 197 | 179 | 209 | 177 |
| 'NIBERS' | 24 | 0 | .079 | 813 | 0 | 0 | 0 | 0 | 0 |
| 'H WRK PIP' | 16 | 0 | 1.093 | 5687 | 5240 | 203 | 223 | 223 | 243 |
| '5 T LIFTIN' | 16 | 0 | .133 | 742 | 742 | 0 | 0 | 0 | 0 |
| 'MTWS' | 22 | 0 | .948 | 1818 | 506 | 542 | 580 | 620 | 664 |
| 'FLT AIR ST' | 16 | 0 | 1.573 | 14051 | 4072 | 148 | 32 | 20 | 20 |
| 'AAV SIGHTS' | 4 | 0 | 11.949 | 150 | 5930 | 31566 | 41967 | 33802 | 9835 |
| 'RM NEUTRAL' | 17 | 0 | .266 | 0 | 0 | 0 | 0 | 4 | 2404 |
| 'AAV NBC SY' | 4 | 0 | 3.643 | 14 | 16797 | 16810 | 13065 | 407 | 212 |
| 'OPTIC TEST' | 12 | 0 | .920 | 3725 | 3850 | 4668 | 73 | 19 | 13 |
| 'TSC - 120' | 12 | 0 | 2.931 | 34149 | 4473 | 526 | 202 | 202 | 202 |
| '5-TON SLEP' | 16 | 0 | 67.806 | 0 | 84363 | 177617 | 212453 | 250686 | 224981 |
| 'EST' | 5 | 0 | 3.930 | 0 | 0 | 0 | 0 | 0 | 53049 |
| 'ESS GROUND' | 14 | 0 | 5.390 | 10175 | 23647 | 18008 | 2815 | 7997 | 8081 |
| 'ROLLER COM' | 17 | 0 | .740 | 12563 | 207 | 48 | 0 | 0 | 0 |
| 'CTIF-TACT' | 16 | 0 | 2.477 | 22278 | 22185 | 100 | 128 | 137 | 100 |
| 'A/C SMV-36' | 17 | 0 | .296 | 2782 | 2875 | 0 | 0 | 0 | 0 |
| '.45 HANDGU' | 7 | 0 | .533 | 0 | 0 | 3847 | 1650 | 1700 | 1950 |
| 'D7G MB PIP' | 17 | 0 | .059 | 676 | 125 | 127 | 125 | 125 | 61 |
| 'MILES' | 22 | 0 | 9.586 | 16342 | 15282 | 16222 | 17162 | 18102 | 19042 |
| 'COM CARGO' | 27 | 0 | .812 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 |
| 'HV MG IMP' | 9 | 0 | .635 | 8003 | 8004 | 0 | 0 | 0 | 0 |

| | MA | STYR | BV | 94 | 95 | 96 | 97 | 98 | 99 |
|---|---|---|---|---|---|---|---|---|---|
| 'NDI RADAR' | 11 | 0 | 13.477 | 47229 | 142668 | 135478 | 6224 | 3254 | 3083 |
| 'RDR ECCM A' | 11 | 0 | .263 | 3080 | 616 | 3080 | 0 | 0 | 0 |
| 'AUTO ENTRY' | 26 | 0 | .250 | 2202 | 514 | 894 | 515 | 515 | 515 |
| 'OPT DISK S' | 24 | 0 | .041 | 535 | 9 | 9 | 284 | 134 | 134 |
| 'HAWK LOADE' | 21 | 0 | .683 | 7675 | 7680 | 3871 | 27 | 0 | 0 |
| 'SMART - T' | 12 | 0 | 2.425 | 0 | 0 | 1000 | 800 | 26432 | 20046 |
| 'VXI PIP' | 28 | 0 | 1.100 | 5649 | 706 | 1656 | 10600 | 15870 | 185 |
| 'AAWS-M' | 9 | 0 | 22.407 | 2009 | 72395 | 138964 | 180680 | 178487 | 110070 |
| 'AAV UPGUNN' | 4 | 0 | 7.126 | 0 | 6099 | 33694 | 47527 | 41133 | 15190 |
| 'TANK CR TR' | 22 | 0 | .230 | 0 | 0 | 5106 | 80 | 160 | 130 |
| 'MSSS-1' | 11 | 0 | 3.423 | 0 | 0 | 99852 | 3531 | 1120 | 725 |
| 'SRAW' | 9 | 0 | 3.556 | 0 | 0 | 7193 | 43718 | 45238 | 45270 |
| 'MSC-63 DS' | 12 | 0 | .862 | 5058 | 9764 | 8835 | 2894 | 2148 | 1772 |
| 'M88A1 RECO' | 3 | 0 | 4.092 | 57421 | 54219 | 102 | 86 | 87 | 88 |
| 'M/LOG AIS' | 24 | 0 | .056 | 466 | 466 | 466 | 443 | 443 | 443 |
| 'TAOM TR' | 22 | 0 | .071 | 0 | 0 | 0 | 2370 | 10 | 70 |
| 'AAV CR TR' | 22 | 0 | .139 | 0 | 0 | 0 | 4910 | 200 | 160 |
| 'MRT' | 12 | 0 | .287 | 2260 | 2880 | 3603 | 3811 | 1407 | 1311 |
| 'ELEC SENSR' | 26 | 0 | .500 | 4273 | 5730 | 3017 | 2952 | 3746 | 2528 |
| 'AV EQ' | 22 | 0 | .075 | 430 | 747 | 747 | 999 | 751 | 663 |
| 'RADIO TRUN' | 25 | 0 | 3.736 | 37065 | 37070 | 37050 | 37045 | 37045 | 0 |
| 'CTIS' | 16 | 0 | .107 | 535 | 1636 | 1674 | 1520 | 1166 | 664 |
| 'PIPE LAUNC' | 17 | 0 | .207 | 0 | 0 | 0 | 14706 | 37 | 11 |
| 'TCO' | 12 | 0 | .569 | 13699 | 9322 | 6210 | 2953 | 2439 | 1098 |
| 'GP RADIO R' | 12 | 0 | .224 | 25 | 515 | 5956 | 5975 | 5481 | 395 |
| 'MIPS/MILOG' | 13 | 0 | .948 | 7203 | 10184 | 11445 | 9544 | 7078 | 4973 |
| 'PMS' | 21 | 0 | .455 | 7397 | 8607 | 10769 | 9796 | 5296 | 957 |
| 'CONTR LIFT' | 18 | 0 | .370 | 34966 | 586 | 586 | 586 | 586 | 586 |
| '1413 PLRSD' | 12 | 0 | .862 | 30095 | 37119 | 17949 | 488 | 488 | 488 |
| 'LAV-E' | 5 | 0 | .734 | 0 | 0 | 0 | 0 | 36837 | 41299 |
| 'SMAW MOD 1' | 9 | 0 | .197 | 0 | 10573 | 9902 | 1339 | 11 | 11 |
| 'DEMNS' | 23 | 0 | 3.587 | 0 | 0 | 0 | 0 | 0 | 85511 |
| 'AIRFLD TR' | 22 | 0 | .004 | 0 | 0 | 0 | 0 | 500 | 0 |
| 'LAV-AD' | 21 | 0 | 6.207 | 237769 | 220760 | 28559 | 22771 | 23582 | 18932 |
| '155 LTWT H' | 2 | 0 | 3.556 | 0 | 0 | 0 | 1000 | 9929 | 26200 |

| | MA | STYR | BV | 94 | 95 | 96 | 97 | 98 | 99 |
|---|---|---|---|---|---|---|---|---|---|
| 'CALS' | 24 | 0 | .119 | 4115 | 3945 | 2570 | 2522 | 2092 | 1985 |
| 'M WRK PIP' | 16 | 0 | .080 | 127 | 11313 | 72 | 72 | 72 | 72 |
| 'WELDER TRL' | 17 | 0 | .059 | 0 | 0 | 0 | 0 | 4976 | 4925 |
| 'M198 HOWIT' | 2 | 0 | .087 | 14915 | 77 | 0 | 0 | 0 | 0 |
| 'DMS WKSTAT' | 25 | 0 | .138 | 3800 | 5180 | 4490 | 4380 | 3230 | 2820 |
| 'AUTO ID TC' | 24 | 0 | .150 | 4751 | 4751 | 5022 | 5022 | 5022 | 5022 |
| 'NBC MODERN' | 6 | 0 | 4.588 | 162292 | 162283 | 162289 | 162275 | 162268 | 162268 |
| 'DTSFO' | 22 | 0 | .058 | 0 | 0 | 0 | 0 | 12007 | 95 |
| 'LAV-105' | 1 | 0 | 3.233 | 166244 | 199294 | 185275 | 14870 | 12692 | 12572 |
| 'SANDY RUN' | 22 | 0 | .455 | 0 | 44170 | 24106 | 19022 | 3282 | 3276 |
| 'RAAM' | 9 | 0 | .109 | 0 | 0 | 0 | 7338 | 8772 | 8812 |
| 'M1A1 BLOCK' | 3 | 0 | 4.003 | 163251 | 233322 | 228051 | 218645 | 93210 | 10392 |
| 'ANTENNA TW' | 12 | 0 | .057 | 0 | 7400 | 114 | 124 | 124 | 124 |
| 'TOW 2B MIS' | 9 | 0 | .438 | 59858 | 60049 | 241 | 165 | 0 | 0 |
| 'UMPT' | 22 | 0 | .047 | 0 | 0 | 0 | 0 | 0 | 17945 |
| 'FAC TR' | 22 | 0 | .028 | 0 | 6572 | 357 | 310 | 290 | 270 |
| 'TOW 2A MIS' | 9 | 0 | .197 | 60199 | 56329 | 391 | 218 | 0 | 0 |
| 'PORT TECHC' | 12 | 0 | .003 | 1645 | 90 | 90 | 85 | 71 | 71 |
| 'AN/TRC/170' | 12 | 0 | .045 | 0 | 26830 | 434 | 434 | 434 | 434 |
| 'TAMP' | 9 | 0 | .088 | 34568 | 30280 | 30293 | 30306 | 30319 | 30336 |
| 'SINCGARS' | 12 | 0 | .006 | 14021 | 0 | 0 | 0 | 0 | 0 |
| 'MINI HH RA' | 12 | 0 | .029 | 0 | 17989 | 19325 | 18791 | 18032 | 15627 |
| 'RDR DISPLA' | 11 | 0 | .000 | 2420 | 2420 | 0 | 0 | 0 | 0 |
| 'AUTO KD RG' | 22 | 0 | .000 | 0 | 0 | 0 | 0 | 0 | 4050 |
| 'WAR GAMES' | 22 | 0 | .000 | 264 | 259 | 259 | 259 | 259 | 259 |
| 'HW RPL MWR' | 24 | 0 | .000 | 0 | 0 | 0 | 0 | 0 | 0 |
| 'HW REP EQ' | 24 | 0 | .000 | 0 | 0 | 0 | 0 | 0 | 0 |
| 'SW RPL' | 24 | 0 | .000 | 0 | 0 | 0 | 0 | 0 | 0 |

;

```
TABLE COMPETE(NUM,I)  displays combinations of initiatives
                      from which only one initiative can be
                      purchased (these initiative names are
                      used for example purposes only)

            'GPS-S'     'AN/TRC-140'    'LAV-AD'    'LAV-105'
      1        1            1              0            0
      2        0            0              1            1
      3        0            0              0            0
      4        0            0              0            0 ;

TABLE DEPENDENT(I,J)  initiatives j that are extensions
                      additions or complements to initiative
                      i (these initiative names are used for
                      example purposes only)

                  'GPS-S'  'NBC HAZ'   'FUEL DEL'   'ELECT TMDE'
  'GPS-S'            0         1           0             0
  'NBC HAZ'          0         0           0             1
  'FUEL DEL'         0         0           0             0
  'ELECT TMDE'       1         0           1             0 ;


TABLE COMPLEMENT(NUM,J)  groups of initiatives that must all
                         be purchased if any initiative i is
                         purchased (these initiative names are
                         used for example purposes only)

                  'GPS-S'  'NBC HAZ'   'FUEL DEL'   'ELECT TMDE'
          1          1         1           0             0
          2          0         1           1             1;
*         3          0         1           1             0
*         4          1         0           1             0
*         5          0         0           1             1;


PARAMETER BL(Y)   budget limit in year y

        /  94     527198
           95     548015
           96     608715
           97     758027
           98     881113
           99     928507   /  ;

PARAMETER OFFSET(PR)     counter for looping assignments to
                         determine the associated costs for
                         each initiative for each schedule

OFFSET(PR) = ORD(PR)-1;
```

```
PARAMETER INFLATION(Y)  inflation factor costs

    / 94        1.03420
      95        1.06563
      96        1.09973
      97        1.13492
      98        1.17124
      99        1.20871   /  ;

PARAMETER COST(I,S,Y)  cost of initiative i with schedule s in
                        year y

   LOOP(I,
        LOOP(Y,
             LOOP(S$(ORD(S) LE 1),
                  LOOP(PR,
                    COST(I,S+OFFSET(PR),Y+OFFSET(PR)) =
                      DATA(I,Y)*(INFLATION(Y+OFFSET(PR))
                                           /INFLATION(Y));
                  );
             );
        );
   );
*OPTION COST:0:2:1; DISPLAY COST;
```

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